SEVENTEENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY.

PART II.—ECONOMIC GEOLOGY AND HYDROGRAPHY.

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BY

WALDEMAR LINDGREN.

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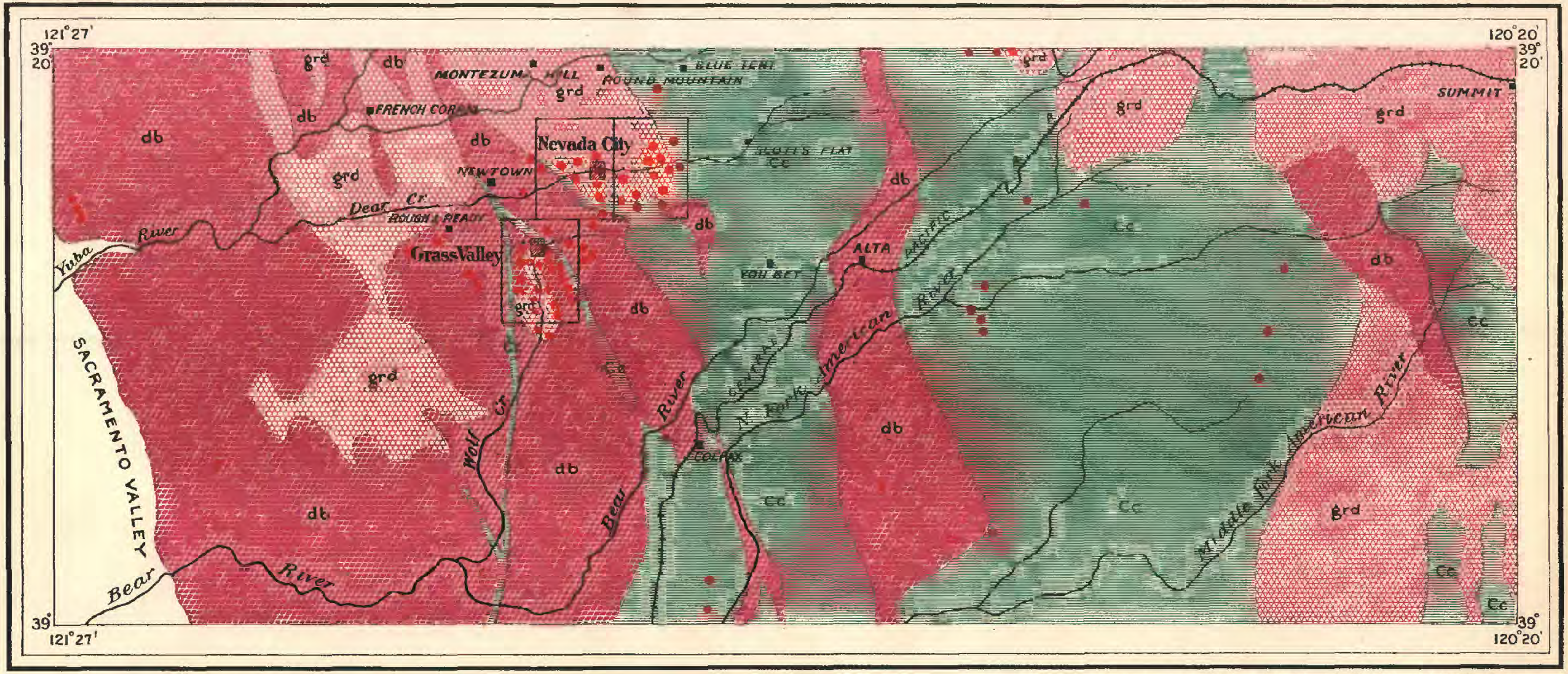

MAP OF PART OF SIERRA NEVADA, SHOWING PRINCIPAL BEDROCK FORMATION AND LOCATION OF SPECIAL SHEETS

BY W. LINDGREN.

grd — GRANODIORITE.

db — DIABASE, PORPHYRITE, GABBRO, DIORITE, SERPENTINE AMPHIBOLITE.

Cc — SEDIMENTARY ROCKS, CHIEFLY JURATRIAS, JURA AND CARBONIFEROUS.

• • • — GOLD-QUARTZ MINES.

Scale of miles.

5 0 5 10 15

J. OTTMANN LITH. CO. PUCK BLDG N.Y.

THE GOLD-QUARTZ VEINS OF NEVADA CITY AND GRASS VALLEY DISTRICTS, CALIFORNIA.

By WALDEMAR LINDGREN.

CHAPTER I.

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

The field work on which this report is based was begun September 20, 1893, and continued without interruption until June 28, 1894. The topographic maps used were prepared in 1891 by Messrs. A. F. Dunnington and R. B. Marshall, with triangulation by Mr. E. M. Douglas, on a scale of $\frac{1}{14400}$, or about 4 inches to the mile. They comprise three sheets, each embracing about 12 square miles, named respectively the Nevada City, Banner Hill, and Grass Valley sheet. The geological and topographic maps, the latter with the outline of mining claims indicated, have been published as a folio of the Geologic Atlas of the United States. For present purposes a map on the reduced scale of $\frac{1}{28800}$ has been prepared from the full-size sheets of the folio.

The chemical analyses have been made by Messrs. W. F. Hillebrand, H. N. Stokes, George Steiger, and Peter Fireman.

To the mine owners and superintendents of the districts many thanks are due for the courtesy and assistance extended by them in the work of examining the mines. I also take great pleasure in acknowledging my special obligation to Mr. E. C. Uren, of Grass Valley, and Messrs. W. F. Englebright and W. W. Waggoner, of Nevada City, for much valuable information and cooperation.

GEOGRAPHIC POSITION.

The important gold-mining districts here described are located in Nevada County, on the long western slope of the Sierra Nevada, at an average elevation of 2,500 feet and about 15 miles north-northwest of the town of Colfax, on the Central Pacific Railroad.

The map appended to this paper shows the topography and geology on a scale of about 2 inches to the mile. The northern part comprises the Nevada City sheet on the west and the Banner Hill sheet on the east. The southern and smaller part consists of the Grass Valley sheet; the small area mapped outside of the northeastern corner of this sheet is referred to as the Brunswick tract.

TOPOGRAPHY.

RELIEF.

The dominating features in the northern part of the tract are the two long ridges whose crests descend gently westward—the Harmony Ridge, near the northern boundary, and the Banner Hill-Towntalk Ridge, near the southern boundary. The northern ridge sinks with a gradual slope from an elevation of 3,660 feet to 2,840 feet at the western boundary line of the Nevada City map, and is cut in two by a gap north of Nevada City. A conspicuous pyramidal hill, the Sugarloaf, with an elevation of 3,075 feet, stands in the middle of the gap and reaches at its summit the gradient of the ridge line. The southern ridge, beginning at an elevation of 3,600 feet, is somewhat wider than the northern, and has at the western boundary line of the map an elevation of 2,700 feet. Near Banner Hill this ridge is cut in two by the narrow canyon of Little Deer Creek; farther west several gaps are cut across it, the most prominent one being that at Towntalk. The average slope of the ridge line is 1½°. At the eastern boundary of the Banner Hill district the ridges approach each other, and are in fact separated only by the deep canyon of Deer Creek. In the southeast corner of the Banner Hill tract, towering 500 feet above the ridges, stands the isolated and conspicuous Banner Hill (elevation 3,904 feet). From the edges of the ridge tables steep slopes lead down to the watercourses, steepest as a rule near the summit, then flattening out somewhat, then again becoming steeper toward the stream bed. The distance between the ridges is greatest at the western edge of the Nevada City tract, and here, as well as south of Nevada City, the relief is less accentuated.

The general relief of the Grass Valley tract is gentler and the outlines are more undulating than those of the region described above. The elevations range from 3,080 feet on the summit of Osborne Hill to 2,080 in the bed of Wolf Creek, at the southern boundary. The northeastern part consists of a series of rather flat-topped ridges, 200 to 300 feet high, with comparatively steep slopes toward the watercourses. The larger, southwestern part may be considered as an undulating plateau, with somewhat irregular hills and ridges rising to a height of 100 or 200 feet above the general level. In this plateau the principal drainage line has cut a canyon, which in some places is narrow and steep, and the depth of which does not exceed 300 feet. Rising high above the other relief and occupying a position similar to that of Banner Hill, stands the high ridge of Osborne Hill.

DRAINAGE.

The principal stream is Deer Creek, which traverses the middle of the region from east to west, and which, 12 miles farther west, empties into the Yuba River. The total fall of the stream from the eastern side of the Banner Hill tract (elevation, 2,840 feet) to the western side of the Nevada City tract (elevation, 2,160 feet) is 680 feet, or about 100 feet to the mile. The fall is by no means uniform, however. In the steep canyon in the eastern part of the Banner Hill tract it is 150 feet to the mile; thence down to Nevada City about 100 feet to the mile; from Nevada City to the Providence mine, through another narrow canyon, the fall is 150 feet to the mile; and from the Providence down to the edge of the tract it is but 53 feet to the mile, the creek meandering over gravelly flats. Lateral ravines, usually steep and narrow, lead to the creek from north and south. A somewhat larger tributary is Little Deer Creek, which heads in the vicinity of Banner Hill. South of Towntalk the drainage is toward Bear River, the ravines forming the northern headwaters of Wolf Creek, a tributary of that river. Southeast of Banner Hill the steep ravines lead down toward Greenhorn Creek, also a tributary of Bear River. The larger part of the area in the southern part of the tract is drained by Wolf Creek, a tributary of Bear River. From the city of Grass Valley it runs south to the limit of the tract without larger tributaries. At Grass Valley it forks into two creeks, which have a general east-west direction. The fall varies from 50 feet to the mile in the Grass Valley basin to 130 in the vicinity of the Omaha mine. The smaller tributaries to the creek show a feature which is also marked in the other two tracts, though to a less extent; they flow with gentle grade over the undulating, plateau-like country, even forming marshes at their sources, but on approaching the main stream they descend to it with a steep, torrential grade. East of Osborne Hill the drainage is toward Rattlesnake Creek, a tributary of Wolf Creek. The extreme northwestern corner drains to Deer Creek.

VEGETATION.

The vegetation is of generally uniform character throughout the district, and consists predominantly of a second growth of yellow pine (*Pinus ponderosa*), the much more luxuriant growth once covering a large part of the ground having been cut for mining purposes since 1849. A few large white-oaks are found on the more open flats, and a strong bushy growth of chaparral (Manzanita and Ceanothus) covers some of the hills. The serpentine ridges have a separate and peculiar vegetation of digger-pine (*Pinus sabiniana*)—elsewhere rarely growing above 2,000 feet—yew, stunted oak, and thorny bushes.

LITERATURE.

The references to the mining industries of the districts are very scattered and consist chiefly in descriptions of individual mines. The more important of them are contained in the following list. In the preparation of this report the statements in Bean's Directory, Raymond's and J. Ross Browne's reports, Burchard's mint reports, and the reports of the State mineralogist have been frequently consulted and used. Bean's

Directory is unquestionably the best and most extensive as well as the most reliable report extant of the districts up to the year 1866. In these publications the geological features generally occupy a very subordinate space, most observations being confined to character of veins and ore shoots, production, and technical data.

W. P. BLAKE. Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean, Vol. V, p. 268.

Notes made in 1853. Contains tatements in regard to the Empire and Gold Hill veins, etc.

JOHN S. HITTELL. Mining in the Pacific States of North America. San Francisco, 1861. 224 pages.

P. LAUR. Du gisement et de l'exploration de l'or en Californie. Ann. des mines, Vol. III, 1863, p. 412.

Notes from many mines in the vicinity. Advocates Tertiary age of quartz veins and gradual decrease of tenor in depth.

J. ROSS BROWNE. Report upon the mineral resources of the States and Territories west of the Rocky Mountains. Washington, 1867.

Contains notes on many mines of the district, tables of production and stamps, statements on early mining laws, etc.; also a résumé by William Ashburner on the Grass Valley mines.

J. ROSS BROWNE. Report upon the mineral resources of the States and Territories west of the Rocky Mountains. Washington, 1868.

Contains notes of many mines in the district, chiefly from Bean's Directory.

BEN SILLIMAN, Jr. Notes on the Grass Valley mining district. Am. Jour. Sci., 2d series, Vol. XLIV, pp. 236–244. 1867.

Contains description and notes of several Grass Valley mines, notably of the Eureka; notes in regard to the geology of Grass Valley, etc. Professor Silliman speaks of the greenstones as probably altered sediments, refers to the presence of syncline and anticline, and considers the quartz veins as conforming to the stratification. The jointing or sheeting has evidently been mistaken for stratification. Occurrence of ore shoots is excellently explained, and the view of impoverishment in depth is combated.

BEAN'S HISTORY AND DIRECTORY OF NEVADA COUNTY. Compiled by Edwin F. Bean. Nevada, 1867.

An excellent book, giving historical data of the development of the district, as well as detailed notes in regard to nearly every vein and placer then worked, chiefly in regard to yield and ownership. Out of print and very rare.

R. W. RAYMOND. Report on the mineral resources of the States and Territories west of the Rocky Mountains, Vols. I to VIII, comprising 1869–1877.

Contains numerous notes in regard to mines of the district.

AMOS BOWMAN. Report on the properties and domain of the California Water Company, situated on the Georgetown divide. San Francisco, A. L. Bancroft & Co., 1874. Also in Raymond reports, Vol. VII, 1879, pp. 441–470.

Contains a few notes on Grass Valley mines and many references to other localities in the Gold Belt. Also contains a map showing strike of the most important veins of the Gold Belt. Book very rare and out of print.

H. C. BURCHARD. Report of the Director of the Mint upon the statistics of the production of the precious metals in the United States. 1881, 1882, 1883, 1884.

Contains numerous notes, chiefly on the production of Nevada City and Grass Valley mines.

J. D. WHITNEY. The auriferous gravels of the Sierra Nevada of California. Memoirs. Mus. Comp. Zool. Harvard Coll., Vol. VI, No. 1. Cambridge, 1880.

Notes and description of gravel mines in the districts, by J. D. Whitney and W. H. Pettee.

REPORTS OF THE STATE MINERALOGIST OF CALIFORNIA. Sacramento, Cal. Vols. I to XII, 1880 to 1895.

Numerous notes and descriptions of quartz and placer mines in the district, by Melville Attwood, J. B. Hobson, and E. A. Wiltsee. Also a paper on the "Lithology of Wall-rocks," by Melville Attwood, describing the Eureka and Idaho mines (8th Ann. Rept., pp. 771-784.) Also a map by Ross E. Browne, of the Harmony gravel mines (12th Ann. Rept.).

J. ARTHUR PHILLIPS. The mining and metallurgy of gold and silver. London, 1868.

Contains notes from personal observation on some Grass Valley mines, and also excellent observations on ore shoots, etc. Shows that the gold ores do not decrease in tenor with depth.

F. G. CORNING. The gold quartz mines of Grass Valley, Cal. Eng. and Min. Jour., Dec. 11, 1886, p. 418.

E. REYER. Ueber die Goldgewinnung in Californien. Zeitsch. für Berg-, Hütten- und Salinenwesen im preuss. Staate, Vol. XXXIV, pp. 1-28, 1886.

Geological sketch of Grass Valley and Nevada City; notes on Eureka and Idaho mines. The determination of rocks is not altogether satisfactory; data presented apparently showing gradual decrease in value of ores in depth.

W. M. COURTIS. Gold quartz. Trans. Am. Inst. Min. Eng., Vol. XVIII, pp. 639-644, Oct., 1889.

Describes microscopic sections of gold-bearing quartz from Grass Valley and other places.

NEVADA COUNTY MINING REVIEW. Published by the Daily Morning Union. Grass Valley, 1895.

Contains short descriptions of the various mines in operation at the present time.

HISTORY.[1]

Previous to the middle of the present century this region, as well as the whole Sierra Nevada, was an unbroken wilderness; the region above an elevation of 2,000 feet was covered with magnificent forests of sugar pine, yellow pine, and fir. Nevada City and Grass Valley were located at the lower limit of this luxuriant and virgin forest.

Once opened up by the army of gold seekers, the progress of the country was rapid; marvelous indeed are the changes wrought in the short forty-eight years elapsed since the discovery of the gold in 1848.

The first discovery of gold in the Sierra Nevada is, as is well known, credited to J. W. Marshall, who on January 19, 1848, found some nuggets in the mill-race while constructing a sawmill at Coloma, Eldorado County, for General Sutter, of Sutter's Fort, now Sacramento.

The first gold found within the boundaries of Nevada County is said to have been panned out by Jonas Spect on Rose Bar, on the Yuba River, north of Smartsville, June 2, 1848. Marshall himself is stated to have visited Nevada County in the summer of 1848, while escorting a party of immigrants across the mountains. He camped on Deer Creek, near where Nevada City now stands, and tried a few pans of dirt, finding gold each time. In October, 1848, two prospectors came up Wolf Creek and camped a short time near where the Eureka and Idaho mines are now located.

During the summer and fall of 1849 the miners gradually worked up along the Middle and South Yuba, Bear River, Deer Creek, and their

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[1] In the compilation of this brief historical review the sources mentioned above have been freely drawn upon.

principal tributaries. Several men were camping at Boston Ravine and Badger Hill, Grass Valley. Dr. Caldwell built the first store where Nevada City now stands, and sawmills were erected 4 miles south of Grass Valley. From that time the development of the districts, at first based principally upon the alluvial placer mines, went rapidly forward. In March, 1850, an alcalde was elected under the Mexican law at Caldwell's store, and the camp received its name of Nevada. In April of the same year the first hotel in Nevada City was erected. It was built of rifted pine boards, the whole house, 8 feet front and 48 in depth, being taken from one tree. The house opened on May 1 with 40 guests, the moderate price of board and lodging being $25 per week.

A town, called Coyoteville, grew up on the gravel hills in the northwestern part of the present Nevada City as soon as it was found that the hill gravels were rich. Several thousand men rushed in during 1850. Sawmills were erected, and the lumber sold at $200 per 1,000 feet. In the summer of 1850 a church was organized, and a paper appeared in 1851. In 1853 the first brick building was erected, and telegraphic communication with Sacramento and Marysville was established. In 1856 there were 907 occupied houses in Nevada City.

In Grass Valley several stores were opened in 1849 and 1850. The first town election was held in November, 1850. The first church was organized in 1851, and a school with 12 pupils opened in a log cabin the same year. After 1851 the growth of the town was very rapid. Like Nevada City, it was, however, subject to many fluctuations, caused by several rushes of the miners to newly reported gold regions, and by periods of depression and activity in the quartz-mining business.

In 1880 there were 20,833 inhabitants in Nevada County; in 1890, according to the last census, 17,369. This decrease is directly due to the cessation of hydraulic mining, prohibited shortly after the census of 1880 by the Federal courts, on account of damage wrought to the lowlands of Sacramento Valley.

Grass Valley township had in 1880 a population of 6,688; in 1890, 6,798. The population of the city is not given separately. Nevada City township had in 1880 a population of 5,506; in 1890, 4,013. The population of Nevada City is given as 4,022 in 1880, and 2,524 in 1890. Since 1890 both cities have increased not inconsiderably in population, due to the renewed interest in quartz mining.

DEVELOPMENT OF MINING INTERESTS.

PLACER MINING.

During the first years the alluvial placer mines furnished the largest amount of gold; in both districts such mines were actively worked during the first and even the second decade after the discovery. Very soon, however, the older, Tertiary hill gravels were discovered; the deposits of these were far richer and more abundant at Nevada City than in Grass Valley. Between 1856 and 1860, and between 1865 and

1870, the old channels on the Alta, Towntalk, and Independent hills, near Grass Valley, were worked by the drifting process. Very little hydraulic work was done about Grass Valley. At the present time there are practically no placer mines working in that vicinity.

As early as 1851 the hill gravels above Nevada City, both on the south and on the north side of the Sugarloaf, were discovered, and the town of Coyoteville, already alluded to, was established on the eastern end of Lost Hill. The methods of mining were at first primitive, small shafts being sunk and low drifts run in different directions. Sluices, the first improvement on the pan, rocker, and long-tom, were first used, it is said, in the Coyoteville diggings. In 1853 the first experiments in hydraulic mining, or sluicing with water under high pressure, were made in Nevada City, on American Hill, by E. G. Matteson. During the sixth and seventh decade hydraulic mining was carried on extensively about Nevada City. Writing in 1866, Bean remarks in his directory: "The placer mines are still worked quite extensively and are the main reliance of a large proportion of the population. There are a few companies conducting operations on a large scale, and generally with success, besides numerous independent miners working the gulches and ravines." At this time hydraulic plants were in operation on American Hill, Wet Hill, and Lost Hill; extensive ground sluicing was carried on on the head waters of Brush Creek, about Selby Flat, where the shallow gravels were extraordinarily rich. In 1858 to 1860 the rich Nebraska ground of the Manzanita channel was drifted. In 1870 the hydraulic mine on the Manzanita channel was being worked. The last hydraulic work about Nevada City at the time of the suppression of hydraulic mining was in the extreme northwest corner of the large hydraulic area on American Hill, and is referred to as Hirshmann's Cut. Since 1890 several drift mines have been in operation on the Harmony Ridge, notably the East and the West Harmony mines.

QUARTZ MINING.

The first find of gold-bearing quartz was made on Gold Hill by a German in September, 1850. The piece was sold for $5, and proved to be worth $100.[1] These and other finds were at first not thought much of. But in November, 1850, a rich ore shoot was struck on Gold Hill by miners digging a hole for their cabin chimney; pieces of this vein proved to contain $500 per ton. A great excitement followed, and in this and the two following years most of the quartz veins in the vicinity were located. At first the quartz was crushed in mortars with spring pole, and the Huff company took out $20,000 in this way in the winter and spring of 1851.

The first mill was put up in January, 1851. It was a rude affair and

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[1] Letter by Senator A. A. Sargent, written January 1, 1856, and published in the Nevada Transcript, October 30, 1893.

proved practically useless. A second, 8-stamp mill was erected soon after, which was a little more useful. Rock from Gold Hill was crushed in it for $50 per ton. The miners were paid $12 per day. In the following years a number of mills were built, one of the best being erected by Melville Attwood in 1853. In 1853 W. P. Blake writes that several quartz mills were located along Boston Ravine, and describes the process in use at the mill of the Empire mine, which began to work in 1851, and with brief intermissions has continued until to-day. Whitney[1] writes at the same time that with the beginning of 1853 there were at least 20 Anglo-Californian companies in the London market, representing a capital of $10,000,000.

During 1851 there was a great excitement about quartz claims in Nevada City, rich gold quartz having been discovered. The Merrifield, Providence, and Gold Tunnel veins were located, and during the next year expensive reduction works were erected, all of which except the Gold Tunnel mill were conspicuous failures. Over $80,000 were expended by the "Bunker Hill" company on a smelting process, works for which were erected on the present Nevada City claim.

On account of the many failures, quartz mining at Grass Valley and Nevada City received a serious setback. At Grass Valley, where several mills were kept running, the industry slowly revived, but at Nevada City the miners turned their attention to the gravels, and quartz mining was almost neglected. In 1857 Grass Valley was flourishing and Nevada City mines were improving. From 1859 to 1862 the business was depressed and values in both districts depreciated greatly, owing partly to the great Washoe excitement, partly to the flooding of many mines during the winter of 1861–62. Again matters improved, and in 1867 Grass Valley was the most prominent camp in the State. In 1866, according to J. Ross Browne, there were 248 stamps, crushing 71,420 tons of ore, with an average yield of $30 to $35, in Grass Valley, and 142 stamps, crushing 14,200 tons, averaging $25, in Nevada City.

In 1873 (Raymond's report) the Grass Valley district produced about $2,000,000 (estimate of large mines only), raising 60,000 tons of ore, averaging $33, with 1 or 2 per cent sulphurets, while in Nevada City only $67,000 was produced from 9,000 tons of ore, averaging $7.50 per ton.

In 1880, according to the Tenth Census, 28,989 tons of ore were raised in the Grass Valley district, averaging $20.26; in the Nevada City district, 27,814 tons, averaging $22.52; and in the Willow Valley district, 1,630 tons, averaging $40. Neither the Tenth nor the Eleventh Census gives the number of stamps running. From the latter there are no definite data to be obtained, the production of the county only being given.

According to the table by Mr. J. B. Hobson, in the Tenth Annual Report of the State Mineralogist for 1889, there were, during that year,

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[1] Metallic Wealth of the United States, Philadelphia, 1854, p. 142.

211 stamps in Grass Valley, crushing 69,054 tons of ore containing 1,721 tons sulphurets, or 2 per cent, with a total estimated value of free gold and sulphurets of about $1,285,000, or about $18 per ton; in Nevada City, 172 stamps, crushing 33,000 tons of ore containing 1,269 tons of sulphurets, or nearly 4 per cent, with a total value of free gold and sulphurets of about $402,500, or about $12 per ton.

A very decided improvement in the quartz-mining business was noticed in the beginning of the present decade. While in 1885 there were but few mines running and but little prospecting in progress, a great and increased activity was noted at the time this investigation was begun. Two hundred and fifteen stamps were dropping in Grass Valley and 170 in Nevada City during 1893, and several new mills have been erected since then.

Gold Hill and Massachusetts Hill were the principal producers during the first two decades. The Empire has worked almost continuously since 1851. The North Star was in operation until 1872, then again from 1884 to the present time. The Eureka pay shoot began to be exploited in 1864, and has been continuously worked since then in the Eureka, Idaho, and Maryland mines. At Nevada City the Gold Tunnel and California mines were among the earliest worked. The Providence and Nevada City mines have been exploited almost continuously, with short interruptions. The Sneath and Clay and the Pittsburg were large producers during the sixth and seventh decades. The Willow Valley veins have been worked intermittently.

In 1894 the following mines were producing:

NEVADA CITY.

Drift mines.—East Harmony and West Harmony.

Quartz mines.—Champion, Providence, Nevada City, Spanish, Mayflower, Federal Loan, and Pittsburg.

GRASS VALLEY.

Quartz mines.—Maryland, Empire, North Star, W. Y. O. D., Pennsylvania, Electric, Omaha, Slate Ledge, Osborne Hill, and Orleans.

MINING CLAIMS.

The first meeting of miners was held in Grass Valley January 13, 1851, on Massachusetts Hill, when a size of 30 by 40 feet was allowed for all claims, the boundaries in all cases being perpendicular. Later on, claims 100 feet square were allowed. The form of the quartz claims on Massachusetts Hill still shows the outlines of the earliest locations. Still later, in 1852, a uniform rule was adopted by the quartz miners of Nevada County by which "each prospector shall hereafter be entitled to 100 feet on a quartz ledge or vein and the discoverer shall be allowed 100 feet additional. Each claim shall include all the dips, angles, and variations of the vein." (Ross Browne's Report, Washington, 1867, p. 235.) This was still in force in 1866, and in fact until the Federal mining laws were passed in 1872, allowing quartz claims to be 1,500 feet along the vein, with all the dips, spurs, and angles, and 600 feet wide.

PROCESSES OF MINING AND MILLING.

The scope of this paper does not permit a detailed explanation of the processes used in obtaining the gold from the gravel and the quartz. A few notes on the subject may, however, not be amiss for those not familiar with the methods employed.

HYDRAULIC MINING.

This method consists in directing a stream of water under pressure, ranging up to 400 feet, against high gravel banks. The quantity of water in one jet ranges up to 1,000 or even 1,500 miner's inches (10,000 to 15,000 gallons per minute, approximately). The disintegrating power of the jet is often aided by bank blasting, consisting in running small drifts in the bank and exploding heavy charges—up to 25,000 pounds—of black powder. The gravel is then led through a number of sluice boxes, aggregating at least 1,000 feet in length, in which the gold is caught in riffles of cobblestones or wooden blocks by the aid of added quicksilver. There are no data of the yield or cost of the hydraulic mining in Nevada City. Presumably, it was not much different from that of the other large hydraulic mines in the county. The top gravel is usually poor, containing from 2 to 10 cents per cubic yard, while the lowest part on the bed rock may be very rich. The minimum cost is probably about 3 cents per cubic yard.

DRIFT MINING.

This method consists in extracting the richest gravel on the bed rock of the old channels, opened up by means of tunnels, inclines, or vertical shafts. The gravel is rarely worked to a height of over 8 feet, the gold being mostly concentrated near the bed rock. The deposit is blocked out and exploited in a manner similar to the working of horizontal coal seams. The pay gravel is washed in sluices, rarely aggregating more than a few hundred feet in length, or when hard and cemented is crushed in stamp mills.

The cost varies greatly, according to conditions. Under the most favorable circumstances the expenses may be reduced to 90 cents per cubic yard; in mines worked by shafts or inclines, having to hoist the gravel and pump the water, the expense is increased to $2 or $3. The milling of the gravel, when necessary, is usually considered to cost 33 cents per ton.

QUARTZ MINING.

The method almost universally adopted of exploiting the quartz veins is by incline shafts, following the dip of the deposits. Levels are turned usually every 100 feet, and the pay rock is extracted by overhand stoping. Perpendicular shafts are sometimes used to open veins with flatter dip.

The cost of mining varies considerably with the thickness of the vein, the hardness of the country rock, and the depth and amount of water in the mine. The generally narrow veins of Grass Valley necessitate so much dead work that the expenses are rather high. In the large veins of Nevada City the cost is stated in the mineralogist's reports to be $2.50 to $3 per ton, while in the North Star, a representative deep mine with narrow vein, it is $5. In certain mines of Grass Valley, working under disadvantages, it is even more—up to $6 and $7. The cost of mining has decreased considerably in the last twenty years. J. Ross Browne gives the cost at the Empire mine as $8.60 per ton in 1867, while at present it does not exceed $5. The power used is steam, water, or electricity.

MILLING.

The ores from both mining districts are called "free milling"—that is, they contain native gold easily amalgamating with quicksilver. They contain, also, however, a certain percentage of gold chemically combined or very intimately mixed with the metallic sulphurets which make up a small fraction of the ore. However fine the ore is crushed, there is always a certain, sometimes considerable, amount of gold going off with the sulphurets if these are allowed to escape. This was recognized early, and the saving of the gold in the sulphurets has been found the most difficult problem in the milling process.

W. P. Blake described the process in use at the Empire mill in 1853 as follows: The ore, after being roasted in heaps, is crushed in a 16-stamp mill; the pulp passes over blankets, where much gold and pyrites is caught; these blankets are wrung out in water at intervals, and the mixture of gold and pyrites is subjected to amalgamation in pans. From the blankets the pulp passes through a revolving cylinder holding mercury, where a part of the fine gold is amalgamated; finally the pulp is subjected to an amalgamation in a Blaisdell pan holding mercury and iron balls; three-fourths of the gold is caught on the blankets. The gradually elaborated process was in use for many years and is known as the Grass Valley process. W. A. Skidmore describes it as used in the Idaho mill in Raymond's reports for 1869 and 1870: The quartz is crushed very fine; there is no amalgamation in the battery. From the battery the pulp is passed over blankets which are washed out every fifteen minutes. The results from the blanket washings are passed through two Attwood amalgamators, where a revolving cylinder with rakes stirs the mass in a bed of quicksilver. The skimmings of the amalgamators are treated in two Knox pans with chemicals, and here 33 per cent of the gross yield is obtained. The pulp from blankets and amalgamators is passed in contact with revolving cylinders of amalgamated copper plates, and the sulphurets are concentrated on improved Cornish buddles. The sulphurets are finally passed to the chlorination process. The average cost of milling in 1868 was generally over $2.

The chlorination process, obviating the shipping of the sulphurets to smelting works or the wasteful grinding in amalgamating pans, was successfully introduced in this region in 1860 by G. F. Deetken and O. Maltman, and has been in use continually since that time. The sulphurets are subjected to an oxidizing roasting, usually with addition of some chloride of sodium; the roasted ore is exposed to the action of chlorine gas in large vats, and the chloride of gold formed is extracted with water. From this solution the gold is precipitated in a metallic state by means of ferrous sulphate. The silver is leached by calcium hyposulphite and precipitated as sulphide of silver by calcium polysulphide. The charge of treating 1 ton of sulphurets is from $16 to $20. There are several chlorination works to which the miners usually sell their concentrates. Mines with their own chlorination works report the cost to be $8 or $9 per ton.

The process of the modern stamp mill differs considerably from the old Grass Valley process. The ore is crushed by rock-breakers and fed automatically to 900-pound stamps dropping 6 to 7 inches from 80 to 90 times a minute. Amalgamation in battery is commonly used. Thirty to 40 mesh screens are used for the discharge, which is only on one side. From the battery the pulp passes over broad 4 by 6 foot silvered amalgamating plates. From the plates the pulp goes to the vanners, self-discharging concentrators of the endless-belt type, with lateral or longitudinal oscillation. In a few mines, notably the Idaho-Maryland, the tailings from the concentrates are worked over again with different contrivances, but ordinarily they escape directly. The cost of milling has been greatly reduced in the last twenty years. In the North Star 30-stamp mill, under E. A. Abadie, superintendent, the cost during 1887 to 1893 averaged 82 cents per ton. The cost of milling in general may be said to vary between $1 and 50 cents per ton, exclusive of the treatment of the sulphurets.

LOSS OF GOLD.

While the stamp mill has been very much improved and the loss of gold very much lessened, still there is in many cases unquestionably room for improvement. Some mills may work the ore up to 90 per cent of the assay value,[1] but in the majority probably an average of 75 per cent only is recovered, and in individual cases the loss may be much greater. The mines whose ore contains tellurium or much sulphurets are particularly liable to lose much of the finely divided particles; galena is especially liable to escape in the sluices. A strict control

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[1] According to J. H. Hammond, 82 to 95 per cent of the assay value of the ore was saved in the Empire and North Star mills.

over the process by continued assays of ore and tailings is too often lacking. The concentrators are made to work a pulp consisting of grains of all sizes; in larger mills this could be obviated by proper separation of the pulp by streams of ascending water; canvas plants for the saving of the frequently rich, finest slimes are at present rather the exception than the rule. Rich sulphuretted ore, worth $75 and above, should never be milled, but shipped to smelting works; the losses in the mill are in this case always heavy, and may be enormous if tellurium is also present.

THE CYANIDE PROCESS.

Attempts to introduce the cyanide process in this vicinity have thus far not succeeded. For the concentrates the process can hardly compete with the chlorination. The large amounts of tailings to which it could have been applied have been swept down Deer Creek and Wolf Creek instead of being stored up. It is not improbable, though, that it could be used for many of the finest slimes, at present not utilized, as has been done at the Utica mine in Calaveras County.

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PRODUCTION.

To determine correctly the production of any mining district in California since 1849 is a well-nigh hopeless undertaking, so deficient are the statistics. The best that can be done is to present an estimate based upon the known yield of later years and the estimated yield in the earlier times. As the product of these districts form an important part of the total gold production of California, that may first be stated in round figures. The figures for the years 1848 to 1865, inclusive, are taken from the estimate of Dr. H. Degroot;[1] for 1866 to 1878 from the estimates of the Director of the Mint;[2] and from 1879 to the present time the amounts have been determined by the Director of the Mint on the basis of more accurate information. The production is given in millions of dollars.

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[1] Fourth Ann. Rept. State Mineralogist, p. 217.

[2] Eleventh Census, Mineral Industries, p. 40.

Estimated production of gold in California.

Year.	Millions of dollars.	Year.	Millions of dollars.	Year.	Millions of dollars.
1848	5	1865	28	1882	16.8
1849	23	1866	25	1883	14.1
1850	50	1867	25	1884	13.6
1851	55	1868	22	1885	12.7
1852	60	1869	22.5	1886	14.7
1853	65	1870	25	1887	13.4
1854	60	1871	20	1888	12.8
1855	56	1872	19	1889	13
1856	55	1873	18	1890	12.5
1857	54	1874	20.3	1891	12.6
1858	50	1875	17.6	1892	12
1859	48	1876	17	1893	12
1860	45	1877	15	1894	13.6
1861	40	1878	15.3	1895	15.3
1862	38	1879	17.6	Total	1,301.1
1863	35	1880	17.5		
1864	30	1881	18.2		

The production of Nevada County previous to 1881, when the estimates by counties was undertaken by the Mint, can be given only as a rough estimate. A. Delano, a banker and mine owner of Grass Valley, probably better conversant with the facts in question than anyone else, gave in 1873 an estimate of $105,000,000 as the output of Nevada County from 1849 to 1872, which, from its relation to the total gold product, seems very reasonable. From 1873 to 1880 there was an average total gold production of 17 millions in the State, and we may estimate the production of Nevada County during the whole of that period to have been 28.8 millions.

Estimated gold production of Nevada County, 1849 to 1895, inclusive.

Year.	Millions of dollars.	Year.	Millions of dollars.	Year.	Millions of dollars.
1849-1872	105	1886	3.2	1893	2.1
1873-1880	28.8	1887	1.6	1894	1.8
1881	3.7	1888	2.6	1895	1.8
1882	3.6	1889	2.1	Total	171.1
1883	3	1890	2		
1884	3	1891	2.2		
1885	2.6	1892	2		

Still less accurate information is there available for the production of the Nevada City and Grass Valley districts, which always, however, forms the largest part of the sums contributing to the total of Nevada County. A very great amount was taken from the placers in the first decade. It was estimated[1] that up to January, 1855, $3,585,000 had been produced from the placer diggings in the immediate vicinity of Grass Valley, and many millions were also taken from the surface placer mines of the Nevada City district. The Shelby Flat and Brush Creek diggings have yielded several millions; the high gravels of Lost Hill, Wet Hill, and American Hill several more; the Manzanita Channel about 3 millions. Mr. Delano estimates (loc. cit.) the total product of the Grass Valley district from 1849 to 1872 at 40 millions, and that of the Nevada City district to be the same amount, which seems somewhat high when compared with the total estimated output of the county. Mr. William Ashburner estimates[2] the product of the quartz mines of Grass Valley to be not less than 23 millions for the period 1852 to 1866, to which amount Massachusetts Hill alone contributed 7 millions; up to the present date the Eureka-Idaho has produced over 17 millions, the Empire and the North Star probably 5 millions each.

The exact information available is very fragmentary; the production by individual mines has been reported in the Mint reports of 1889 to 1892, inclusive, the later reports giving production by county only.

The following data are obtainable for the gold and silver production:

Gold and silver production of the Nevada City and Grass Valley districts.

Year.	Authority.	Grass Valley district, including Deadmans Flat and Forest Springs.	Nevada City district, including Willow Valley.	Total.	Remarks.
1865	J. Ross Browne	....	$400, 000	....	Quartz mines only.
1866	.....do	a$2,000, 000	a 500, 000	$2, 500, 000	Do.
1870	R. W. Raymond	....	....	1, 587, 000	Do.
1873	.....do	a 2, 000, 000	a 67, 000	2, 067, 000	Do.
1874	.....do	....	....	1, 089, 591	Only principal quartz mines.
1875	.....do	....	....	a 1, 500, 000	Quartz mines only.
1880	Census	587, 260	721, 972	1, 309, 232	Do.
1889	Mint report	1, 066, 600	448, 200	1, 514, 800	All mines.
1890	.....do	726, 750	566, 300	1, 293, 050	Do.
1891	.....do	984, 500	325, 500	1, 310, 000	Do.
1892	.....do	781, 250	323, 800	1, 105, 050	Do.
1893	.....do	840, 400	....	....	Only large quartz mines.

a Approximate.

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[1] Nevada County Mining Review, p. 19.

[2] Rept. J. Ross Browne, 1867, p. 37.

The production of Grass Valley is derived almost exclusively from quartz mines. In the Nevada City district the placer mines still contribute a small part of the product.

Accepting Delano's estimate for the earlier years of 80 million dollars for 1849 to 1872, the estimate for the period 1873 to 1893, inclusive, would be about 33 millions, or a total for the districts of about 113 millions, which I am inclined to consider a very conservative amount rather too small. The quartz mines have certainly contributed 60 per cent of this amount, and perhaps more.

It will be seen that the product of Nevada County has remained at an average of 2 million dollars for the last ten years, also that Grass Valley during the past ten years has produced an average of about $850,000 per year, and Nevada City an average of $400,000 per year.

In the above data the gold and silver productions are not separated, the latter being comparatively insignificant. The Mint reports give the production in value, though the estimation of production by weight in ounces would, perhaps, be a better plan. The silver product of Nevada County for 1894 and 1895 is given as about $400, but it is apparent that the production in reality must be larger. Assuming a production of 50,000 ounces of bullion 850 fine and containing 12.5 per cent silver, which probably is below the average, this bullion would contain 6,250 ounces of silver, and as several of the ores contain much more silver, this value is certainly a minimum. The average production is also generally above 50,000 ounces of bullion.

CHAPTER II.

GENERAL GEOLOGY.

GENERAL FEATURES.

The general geologic features of the region here under discussion are delineated and described in the maps of the Gold Belt, especially on the Smartsville and Colfax sheets, and to them the student desirous of more extended knowledge of the Sierra Nevada must be referred. It is, however, desirable to indicate briefly the connection of the districts here described with the general structure of the surrounding country. Throughout the Sierra Nevada there is one sharp geologic distinction to be drawn. It is the difference between the older rocks—the "bed-rock series," as it is usually termed—on the one hand, and the "superjacent series," or the much younger gravels, sands, clays, and volcanic rocks, on the other hand. The bed-rock series consists of highly altered sedimentary rocks, crystalline schists, and older igneous rocks, on which the superjacent series lies in approximately horizontal position. The rocks of the former series have been subjected to repeated orographic disturbances, and to a great extent have been compressed, broken, and crushed by these forces. The rocks which are now at the surface were once below it, probably thousands of feet; successive uplifts and constant erosion have removed the upper parts of the rock masses and exposed those once buried in the foundations of the range. Rightly to understand the geology this fact must be borne in mind.

THE BED-ROCK SERIES.

While it is comparatively easy to unravel the later (Neocene) history of the Sierra Nevada, the same can not be said of the immeasurably longer periods preceding it. They included successive epochs of quiet sedimentation, when the ocean covered the place where the range now rises; several distinct epochs of intense volcanic action, when the lavas built up mountains of igneous masses; and other epochs during which mountain-building forces lifted and crushed together these sedimentary and igneous products. In these compressed and crushed masses occurred enormous abyssal intrusions of coarse-grained granitic rocks. Animal life, on the remains of which we depend for the identification of the sedimentary formations, was unusually scant during the intervals of deposition, or most of the fossils were destroyed during the metamorphism which the rocks have undergone. Many parts of the Sierra Nevada have, indeed, the aspect of pre-Cambrian complexes—the oldest known—though, from the evidence available, it is certain that the rocks of the range in general are of much younger age.

The Nevada City and Grass Valley district is located in the upper foothills, near the line where the old igneous rocks of the foothill region give place to the wide belt of slaty, sedimentary rocks of the middle range; east of this sedimentary belt the granitic rocks of the highest parts of the range begin. High ridges of fine-grained, dark-green rocks, diabases, and augite-porphyrites form the first foothills of the Sierra Nevada in Yuba and Nevada counties. In the latter county these rocks extend to near Anthony House and Indian Springs, where they are replaced by a belt of coarser-grained granitic rocks (granodiorite, diorite, and gabbro), which terminates along a line drawn by French Corral, Rough and Ready, and Wolf Creek Mountain. Eastward of this line, up to Nevada City and Grass Valley, the geology is very complex; relatively narrow belts of more or less metamorphosed sedimentary rocks, standing at steep angles, alternate with large quantities of fresh or metamorphosed igneous rocks. Near Nevada City this complex is separated from the predominantly sedimentary slates to the east by the rounded southern end of the great intrusive granodiorite mass extending more than 20 miles northward into Butte County. In the southern part of Nevada County the diabases and porphyrites of the foothills extend very far eastward, and an area of these rocks reaches northward, including Osborne Hill, to the east of Grass Valley.

The region of complicated structure begins at Rough and Ready, 5 miles west of Grass Valley, with amphibolites and gabbros; then follows a belt, from one-fourth of a mile to 1½ miles wide, of sedimentary clay-slates and siliceous slates, which, near the North Star mine, enters the Grass Valley tract. A branch of these slates is deflected to the southeast and traverses the northeastern part of the Grass Valley tract. Between Grass Valley and the main clay-slate belt lies a body of diabase and porphyrite about three-fourths of a mile wide, the continuation of which northward, though broken for a short distance by intervening slate masses, is found west of Newtown. East of this diabase belt lies the Grass Valley area of granodiorite, 5 miles long, a rather narrow body of coarse-grained granitic rock, the northerly end of which is found in the city of Grass Valley. Eastward of this comes the great porphyrite and diabase area of Osborne Hill, limited again by the above-mentioned streak of sedimentary slates cutting obliquely across the Grass Valley tract.

The greatest complication is found between Nevada City, Newtown, and Grass Valley. Within this area the rocks may be divided into three groups: (1) The two narrow belts of siliceous clay-slates with steep dip, one following the contact of the Nevada City granodiorite area for a long distance, the other embedded in porphyrites one-fourth of a mile eastward. (2) The diabases and porphyrites, occupying a considerable area to the south of Nevada City and continuing down to the vicinity of the Maryland mine. These dark-green, fine-grained rocks form pointed areas running out northward. The largest, adjoining the first-mentioned slate belt, comes to a point about 3 miles west-northwest of Nevada City. (3) The diorite-gabbro-serpentine complex, beginning north of South Yuba River, forming a lenticular mass 9 miles long and not over 3 miles wide, and running out in several points a short distance east of Grass Valley. The largest part of the latter area consists of a coarse-grained, lighter or darker green diorite or gabbro, or a rock intermediate between the two. In it lie several lenticular masses of serpentine, usually running out to sharp points. The road from Nevada City to Newtown crosses the two largest of these serpentine masses. Less altered pyroxenites and peridotites are found in or near the serpentine. There is excellent reason for believing that all the rocks of this complex are of similar age and origin.

Turning now to the question of the relations of all these different rocks, it should be stated that no fossils have thus far been found in the sedimentary rocks of the district. The greater part of the latter have been referred to the Calaveras formation, which embraces the Paleozoic sedimentary rocks of the Sierra Nevada. Among the Paleozoic rocks the Carboniferous strata doubtless predominate, but the paucity of fossils has permitted identification only at relatively few points. The determination of the rocks in question as "Calaveras," therefore, rests on circumstantial evidence only. These slates of the Calaveras formation are probably the oldest rocks in the district. During a mountain-building disturbance toward the end of the Paleozoic or the beginning of the Mesozoic these beds became folded and compressed. This earliest uplift was associated with the outbreak of igneous rocks, which, indeed, in some localities took place even during the deposition of the Carboniferous beds, but of those igneous rocks there is no positive trace in the region under discussion. It is believed that all of the igneous rocks of Grass Valley and Nevada City are post-Carboniferous, and probably none of them antedate the end of the Juratrias period.

During the last portion of the Juratrias period a large part of the Sierra Nevada was a land area. Part of it, however, was submerged, and in that sea the latest sedimentary division of the bed-rock series—the Mariposa beds—was deposited. These are black, carbonaceous clays, interbedded in places with volcanic tuffs, showing that during their formation volcanic forces were acting. In this district a narrow belt of black clay-slates, interstratified with clastic volcanic material, has been determined as belonging to the Mariposa beds.

After the Mariposa epoch followed a time of the most intense mountain-building disturbance, accompanied by the outburst of an enormous quantity of igneous material of different character and texture. The younger sedimentary rocks were folded and compressed and welded with the older series of the same kind, while intrusive masses were injected in them far below the surface, and volcanoes with thousands of feet of lavas and ash masses were built up on the surface along what are now the foothills of the range.. The diabases and the porphyrites belong to this volcanic period, partly as surface flows and dikes, partly as deep-seated intrusive masses, consolidated as coarser granular rocks far below the surface.

Finally, as the last and farthest-reaching phase of that period of igneous activity, came the intrusion of the large granodiorite masses in the then deep-seated part of the range. This took place on so gigantic a scale that the mind strives with difficulty to comprehend the mechanics of the process. Thus, the granodiorites of Nevada City and Grass Valley are the most recent rocks of the bed-rock series. Finally, after the intrusions of the granodiorite, dynamic forces, acting on the mass with different intensity and in different directions, produced fissure systems in which auriferous solutions ascended and deposited their contents. This forming of the mineral veins was the last phase of the Mesozoic revolution in the Sierra.

By no means all of the rocks of the district are now in the same condition in which they were formed. Successive dynamic forces have acted on many of them, producing deformation and schistose structure. Chemical forces have acted on them in at least three distinct ways, changing their mineral constituents until their original form is sometimes scarcely or not at all recognizable—first, as a result and concomitant of dynamic metamorphism; second, by the heat and mineralizing exhalations of the intrusive granodiorite; third, by the action of the hot auriferous solutions on the rocks adjoining the fissures through which they circulated. Often several or all of these effects have been combined in one locality, rendering very difficult the task of unraveling the changes through which the rock has passed. In the region covered by the Smartsville sheet, in which the larger part of the area described in this folio is located, there has been less of that intense dynamic action producing slaty and schistose structure by compression than in some parts of the Gold Belt farther south. One line along which the rocks have been crushed and rendered schistose extends in a northerly direction through nearly the whole region, and passes some distance beyond the western boundary of the Grass Valley tract. As in certain localities along that line the granodiorite has been rendered schistose, it follows that this line of disturbance was produced later than the intrusion of granodiorite. Another line of schistose structure in the Calaveras formation follows the granodiorite contact south and west of Nevada City. But most of the rocks in the area of the special maps are of massive character.

THE SUPERJACENT SERIES.

At the beginning of the Neocene period the Sierra Nevada formed a mountain range of substantially the same outlines as that of to-day, but of much less height, the summits—located along the same line as the present ones—having an elevation probably of about 5,000 feet, in latitude 38° to 39°. The range had been above water since the end of the Juratrias period, and in its lower part long-continued erosion had reduced it to a hilly, undulating country, frequently broken by high ridges and isolated peaks. A drainage system somewhat similar to the one of the present day had been developed, and auriferous gravels accumulated along the streams from the débris of the numerous quartz veins. The stream receiving the drainage of Grass Valley and Nevada City corresponded closely to the Yuba River, but also embraced the watershed of the upper Bear River. Its southern branch came down from Dutch Flat and You Bet with a northerly direction, crossing Deer Creek at Scotts Flat and the South Yuba at Blue Tent; then turned westward and flowed down to the Great Valley by Badger Hill, North San Juan, French Corral, and Smartsville. During the latter part of the Neocene period volcanic eruptions began near the summit of the Sierra Nevada, and masses of volcanic material began to pour down the river channels. The first material erupted was the light-colored, siliceous rock called rhyolite, which was of comparatively small volume, confining itself as a rule to the river channels. The larger quantity of the eruptives poured out as volcanic muds, which easily found their way down to the foot of the range. On the lower slopes they became mixed with more or less gravel and sand, and their eruptive character is now less apparent. Very heavy flows of this kind found their way down the old South Fork of the Yuba, and part of them flooded a low divide and filled the Nevada City basin. After a short interval, during which considerable erosion took place, the so-called "cement channels" or "channels of the volcanic period" were formed in certain parts of the Sierra, wherever erosion cut through the rhyolitic flows. No such channels have been found in the district here described. Then the period of andesitic eruptions began, and mud flows again poured down from the vents near the divide, at first as dark-colored, fine tuffs and sands, later as a gray or brown tuffaceous breccia, containing, in the foothills as well as in the high range, larger, more or less angular bowlders of the dark-colored porphyritic rock called andesite. These last flows, coming down in rapid succession, flooded everything and covered up the middle slopes to such an extent that only isolated ridges and peaks protruded above them. The whole area here considered was thus once a gently sloping lava field, above which only Banner and Osborne hills protruded. The last of the andesitic flows is supposed to mark the close of the Neocene period. During the volcanic epoch the Sierra Nevada was subjected to a tilting uplift, which at the summit probably amounted to several thousand feet, and the streams at once began the work of cutting into this desolate lava plateau. The directions they took were more generally transverse than formerly. Their similarity to the old drainage was caused by higher protruding ridges of bed rock, which in many places confined the new river to the old valley. This work of canyon cutting has been continued with ceaseless energy until the present time. Not only has much of the enormous lava masses been washed away, but, owing to the uplift, the rivers have cut down far below the old Neocene bedrock surface and created the characteristic features of the Sierra Nevada of to-day. These are deep, abrupt canyons separated by broad or narrow ridges of more gently undulating surface.

In the district described in this folio the sloping ridges—Harmony Ridge and the Banner Hill–Towntalk Ridge—are the only remnants of the lava sheet which once covered nearly the whole region, while the present watercourses, here wholly unlike their Neocene predecessors, are sunk several hundred feet below the Neocene surface. Between the close of the andesitic eruptions and the present day occurred the extensive glaciation of the High Sierra, but the glaciers terminated about 30 miles above Nevada City; and it may be stated with certainty that neither in the Neocene nor in the Pleistocene period have any ice streams extended as far down as the latter place.

CHAPTER III.

THE IGNEOUS ROCKS OF THE BED-ROCK SERIES.

GRANODIORITE.

DEFINITION OF ROCK.

Under the name *granodiorite* are included coarsely granular rocks, intruded and consolidated at considerable depths below the surface, having a normal granitic (eu-granitic) structure, and a mineralogical composition of quartz, soda-lime feldspars, orthoclase, hornblende, and nearly always biotite. Titanite and magnetite are always present as accessory constituents. This rock, which in the Sierra Nevada occurs in enormous areas, forms an intermediate group between the quartz-mica-diorites and the granites, being, however, more closely allied to the quartz-mica-diorite than to the granite. Comparison of numerous analyses from various parts of the Sierra Nevada shows that the chemical composition varies between that of a quartz-mica-diorite and a quartz-monzonite (adamellite, banatite, Brögger). Its geological occurrence and in general entirely similar habit preclude the possibility of dividing it into subgroups.

The rock is very characteristic and can not easily be mistaken. The feldspars are generally white; the quartz is not very conspicuous and does not occur in large grains, as in some granites of the high Sierra; the hornblende is dark-green, often in long, rough prisms; the biotite is of the usual dark-brown color. The general effect is a light-grayish color.

Limits of variation and average composition of granodiorite.

	Limits of variation.	Average composition.
	Per cent.	*Per cent*
SiO_2	59 to 68½	65
Al_2O_3	14 to 17	16
Fe_2O_3	1½ to 2¼	1.50
FeO	1½ to 4½	3
CaO	3 to 6½	5
MgO	1 to [a] 2½	2
K_2O	[b] 1 to 3½	2.25
Na_2O	2½ to 4½	3.50
Remainder		1.75
		100

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[a] Three and one-half, one analysis.

[b] Certain masses in the foothills go below 1 per cent.

NEVADA CITY AREA.

Extent and character of surface.— The Nevada City granodiorite area forms the southern end of a great massif extending northward far up in Butte County. It is generally sharply defined in this region, but in its northern part more basic diorites and gabbros are intimately connected with it by transition.

The rock occupies a large part of the area covered by the Banner Hill and Nevada City sheets. It forms a series of rounded, comparatively gently sloping hills with elevations gradually increasing eastward. Deer Creek crosses the area in a canyon which, south of Willow Valley, near the contact with the sedimentary area, has precipitous and narrow slopes and is over 700 feet deep. In the western course it has more gently sloping sides, the inclination rarely exceeding 12°; a steeper slope is, however, usually noted immediately at the creek, in places forming almost a "canyon within a valley." Little Deer Creek cuts a smaller canyon in the granodiorite farther south.

From Nevada City to the Providence mine the canyon, cut in less disintegrated rock than farther east, is narrow and rocky. The western and southern part of the area is rather gently hilly and undulating, but is cut near Deer Creek by steep ravines.

Macroscopical description.—The normal granodiorite is a fresh, coarsely granular rock of light-grayish color, composed of dark-green hornblende, dark-brown biotite, colorless quartz, and white or slightly yellowish feldspar. The grains average about 2 or 3 mm. in diameter. The hornblende is relatively more abundant than the biotite; both of them sometimes occur in idiomorphic form, the hornblende as thick prisms up to 10 mm. in length, the mica as hexagonal foils up to 3 or 4 mm. in diameter. Small grains of yellow titanite are sometimes noticeable. Pyrite is, on the whole, rare, and occurs only in small grains connected with the hornblende. Copper pyrites have also been noticed in the hornblende, but pyrrhotite does not seem to occur. Near the contacts the hornblende sometimes, though by no means always, increases, giving the rock a more basic aspect. Such is the rock along the contact from Deer Creek northward, and also in the vicinity of the North Banner mine, where it should more properly be called a diorite. The dark spots so frequently seen in granitic rocks abound in certain parts of the area, and are composed principally of feldspar and hornblende; they often show fissures and breaks filled with granodiorite. On the whole, the granodiorite shows but slight variation in the different parts of the area. The outcrops of the less decomposed rock are smooth and rounded.

Microscopical description.—In thin sections the fresh, unaltered character of the rock, compared with others of the district, is very striking. The character is comparatively uniform. The mica is normal, dark-brown biotite, with small though distinct angle between the optical axes; the color is a clear yellowish-brown, without any shade of red. It is sometimes idiomorphic. Local alteration has in places converted some of it to chlorite or muscovite, both appearing as inserted parallel plates. Small fragments of a doubtful mineral are in one slide intergrown with the biotite, showing blue and yellow pleochroism and an extinction of about 45°. The hornblende is green or brownish-green and compact, sometimes roughly idiomorphic and with a maximum extinction of 18° to 20°; occasionally a little chlorite and epidote accompanies it. The hornblende sometimes incloses foils of biotite, but is also occasionally surrounded by biotite. In one specimen 300 feet from the contact in Deer Creek the hornblende shows sharply defined kernels of augite.

The predominating feldspar is plagioclase, forming usually roughly idiomorphic prisms with strong twin-striation and comparatively low symmetrical extinction, hardly ever above 20°. A zonal structure is not common. A micaceous mineral occurs in some as products of incipient decomposition.

The orthoclase is less abundant and occurs as irregular grains; it sometimes contains a slight microperthitic intergrowth of albite; rarely some grains show a very fine and indistinct striation, suggesting the presence of anorthoclase. Microcline does not appear to be present. The quartz forms irregular grains; undulous extinction is seldom noticeable, nor is there on the whole much evidence of strong dynamic action on the rock.

Of accessory minerals, magnetite in irregular, often rounded grains is always present and mostly contained in the hornblende or in the biotite. Iron pyrite is sometimes seen; it is never beyond doubt primary, but always appears associated with the decomposition products of the hornblende. Titanite is quite common, as well as apatite and zircon. The structure is characteristically hypidiomorphic; the mica and hornblende are sometimes, the plagioclase nearly always, partly idiomorphic; these minerals are cemented, so to speak, by a later consolidated mass of orthoclase and quartz. This structure is always characteristic of the granodiorite. Small crystals of plagioclase are occasionally embedded in the mica or in the hornblende. In some specimens a very fine grained micro-pegmatitic intergrowth of quartz and plagioclase is noted as a rim surrounding the end of some of the feldspar crystals.

An important characteristic of the granodiorite is its fresh character, owing to an absence of dynamical and chemical alteration.

The dark spots occurring so frequently, for instance at the quarry at the west edge of the Banner Hill sheet, consist mainly of hornblende (with a little mica) and idiomorphic plagioclase, between the prisms of which lies a little quartz. They also contain much magnetite, and a grain of probably primary pyrite was once noted.

Chemical composition.—A fresh specimen taken near Shurtleff's barn, about 1 mile southeast from Nevada City, analyzed by Dr. W. F. Hillebrand, gave the following result:

Analysis of granodiorite from near Nevada City.

	Per cent.
SiO_2	66.65
TiO_2	.38
Al_2O_3	16.15
Fe_2O_3	1.52
FeO	2.36
MnO	.10
CaO	4.53
SrO	Trace.
BaO	.07
MgO	1.74
K_2O	2.65
Na_2O	3.40
Li_2O	Trace.
H_2O below 110°	.18
H_2O above 110°	.72
P_2O_5	.10
FeS_2	.02
	100.57

The analysis is typical of the granodiorite. The relatively low percentage of MgO (FeO, Fe_2O_3) and CaO is characteristic, as is the fact that the sum of the alkalis exceeds considerably the lime. The TiO_2 is present chiefly as titanite. In view of the fact that the exact composition of the hornblende and mica is unknown, there are not sufficient data for the calculation of the constituents of the rock. The rock contains in estimate:

	Per cent.
$K\ Al\ Si_3O_8$	15
$Na\ Al\ Si_3O_8$	29
$Ca\ Al_2\ Si_2O_8$	15
Hornblende and biotite	16
Quartz	22
Apatite	.24
Magnetite	1.50
Titanite	1
	99.75

The plagioclase is consequently an oligoclase. It should be remarked that the relation between the potassa and the soda is by no means constant. In a specimen from the same area, taken where the Purdons Bridge road crosses Rock Creek, 4 miles north of Nevada City, a partial analysis by W. H. Melville gave 0.89 per cent K_2O and 4.25 per cent Na_2O.

Weathering.—Except along the bottom of the deeper creeks, the granodiorite is very soft and decomposed; in places the decomposition reaches a depth of 200 feet. Especially is this the case in the eastern part of the area, which is covered by a deep dark-red soil in which few remaining harder bowlders lie scattered. This is a true residual soil, derived from decomposition in place, and reaches its greatest depth on the northern slope of the ridges. Beautiful exposures of this decomposition are seen in the hydraulic pits southeast of Canada Hill. The decomposition of the granodiorite seems to have at least two distinct stages. The first consists in loosening the grains to a soft crumbling aggregate. This loosening seems to be due mainly to the decomposition of the feldspar grains. The biotite and hornblende are not much altered. Such is the condition of the rock in the lower foothills. The second stage consists in the complete decomposition of the hornblende and biotite as well as the feldspar. Next to the quartz, the biotite is the most resistant mineral. The ferrous oxides are completely converted into ferric, and the result is a soft, clayey, deep-red material.

In the western part of the area most of the residual soil covering the ground has been swept away; coarse, crumbling, and yellowish rock very frequently comes to the surface, and harder masses frequently show their light-gray, round outcrops through the more decomposed surrounding rock. This peculiar manner of decomposition is well shown in several places. The harder masses are often surrounded by concentric softer shells, as seen near the railroad station at Nevada City. Excellent exposures of very hard, rounded outcrops in predominantly soft rock are seen on the bed rock of the hydraulic diggings half a mile northwest of Nevada City, and similar sharply defined hard masses, usually called "bowlders," are often found in driving tunnels through the soft decomposed granodiorite to reach the Tertiary channels.

Relation to surrounding rocks.—The granodiorite is the youngest member of the fundamental series, little affected by mechanical and chemical changes. It was evidently intruded far below the surface as immense masses or batholites of molten magma, which slowly consolidated and which a long-continued erosion finally exposed. The rocks near the contacts, chiefly the sedimentary rocks, show a most decided and characteristic contact metamorphism, produced by the heat and emanations of the eruption. The contacts are not generally well exposed, on account of the surface decomposition; good exposures are, however, found on both sides of the massif in Deer Creek.

Dikes of granodiorite occur sparingly in the adjoining sedimentary rocks. One, about 20 feet wide, was noted in the bed of Deer Creek, 80 feet east of the contact; this rock is a normal granodiorite, containing fragments of the sedimentary metamorphic rocks through which it breaks out. In the Federal Loan mine, dikes of dark diorite, with large hornblende crystals, break through the sedimentary rocks; these diorites, which contain some pyrite and pyrrhotite, are probably genetically connected with the granodiorite. At the ditch 400 feet above and southeast of the mine the granodiorite sends out dikes or apophyses of somewhat darker dioritic character. A great number of dikes or smaller intrusive masses are noted above the North Banner mine at the head of Little Deer Creek; these consist of usually rather dark granodiorite or quartz-mica-diorite.

A small, apparently intrusive mass on the Scotts Flat road at the divide north of the Federal Loan, and the small dike nearest to the head of Little Deer Creek, have been indicated as diorite on the map. They present, however, some peculiar features, and show great similarity with a rock collected at the extreme edge of the Banner Hill tract, on the road east-southeast of Banner Hill. It is believed that these rocks should rather be referred to the later series of diabases and porphyrites, which frequently carry hornblende.

An excellent instance of a small branching dike of granodiorite is seen on the south bank of Deer Creek below the Providence mill; other dikes occur along the road, just south of the same mill and on the south bank of Deer Creek 400 feet west of it. Intrusive masses of granodiorite in altered diabase are also seen in the Providence mine on the sixth level, on the contact vein, and on the third level of the Nevada City mine in the second crosscut in the foot wall south from the new shaft.

Dioritic facies.—In the vicinity of the North Banner mine the granodiorite becomes more basic and similar to a diorite. At the contact a few hundred feet southwest of the mine it also assumes a finer grain. The small area northeast of the mine inclosed between the andesitic breccia and the sedimentary rocks is a rather dark quartz-mica-diorite. In the area west of the mine, separated from the former by a projecting tongue of slate, the rock is more clearly dioritic and consists of plagioclase and brownish-green hornblende, one of the latter showing a kernel of augite. A little quartz separates the lath-shaped feldspar crystals.

Diorite and granodiorite northwest of the Nevada City mine.—Near the contacts the granodiorite has sometimes, as noted, a tendency toward more basic development, but no extensive change of this kind occurs until beyond the Nevada City mine. From Birchville, 6 miles to the northwest, to the Nevada City mine the granodiorite is adjoined by an area of diorite, with associated gabbros and pyroxenites. At the excellent exposures in Shady Creek, about 2½ miles east-northeast of French Corral, the contact between diorite and granodiorite is clear and sharp, the latter being younger and intrusive into the former. Again, in the canyon of the South Yuba the contact between the two formations is sharp, though it appears to be a fault plane dipping east; but from the river to the Nevada City mine the relations are doubtful. Along a line running due northwest from the mine the granodiorite becomes darker, and changes imperceptibly into dark diorite and gabbro, replaced by pyroxenite at the edge of the Nevada City tract. Thus there is along this line no distinct contact line to be drawn between the granodiorite on one hand and the diorite-gabbro-pyroxenite complex on the other. This is puzzling, for all the other evidence is in favor of the latter being distinctly older than the granodiorites; besides, it contains dikes of the diabase-porphyrite series, which, on the other hand, is distinctly older than the granodiorite. There may, after all, be a contact, although the similarity of the formations and the decomposition of the surface prevent its being noticed.

The diorite dikes near Indian Flat.—In the belt of the schistose greenstones from 1,000 to 2,000 feet west of the granodiorite contact there are two long-drawn bodies of diorite which appear to be intrusive masses; they probably are connected with the granodiorite in origin, and form a facies or product of differentiation of that magma. The rock is dark and coarse, and composed of dark-green uralitic-appearing hornblende and white or greenish feldspar. In thin section large grains of green hornblende and partly idiomorphic plagioclase form the chief constituents. There is much apatite and ilmenite. Some of the hornblende may have been derived from a primary pyroxene, but of this there is no direct proof. A little secondary biotite is noticed in the hornblende.

GRASS VALLEY AREA.

Extent and character of surface.—The granodiorite of Grass Valley forms an elongated area much smaller than that of Nevada City, and extending along Wolf Creek for 5 miles south of Grass Valley. Its width varies from less than half a mile up to nearly 2 miles. A series of rounded hills marks the area on both sides of the more abrupt canyon of Wolf Creek. Compared with the great mass of Osborne Hill, the area marks a depression of old Tertiary date, produced by the more easily disintegrating character of the rock.

Rock description.—The Grass Valley granodiorite differs somewhat in appearance from that of Nevada City. It is a greenish-gray, medium-grained rock, consisting of two kinds of feldspar—pale-red and greenish—black hornblende, and quartz. Only exceptionally, as at the Scotia shaft, does biotite enter into the composition. Small grains of pyrite are not uncommon. The type is practically constant over the whole area.

Under the microscope the plagioclase is rather predominant, usually partly idiomorphic, and often filled with micaceous minerals. The orthoclase hardly ever shows crystal outlines, and is generally fresher than the plagioclase. The quartz is sometimes intergrown with the orthoclase in micropegmatitic structure. Microperthite is also noted, and occasionally a very finely striated feldspar associated with the orthoclase, possibly anorthoclase. The hornblende is the ordinary granitic variety with brownish-green color, frequently converted into chlorite and epidote. Accessories are magnetite, titanite, zircon, and apatite. The first-mentioned mineral is probably somewhat titaniferous, for leucoxene (titanite) has been observed to form from it. Small grains and crystals of pyrite frequently occur, but are probably all secondary. They are closely associated with the hornblende and sometimes surrounded by a chlorite rim.

The structure is typically hypidiomorphic, imperfect prisms of plagioclase and hornblende being partly embedded in orthoclase and much quartz.

The rock on the whole is somewhat less fresh than the granodiorite of Nevada City. Darker dioritic modifications of the rock are rare, but were noted in the branch of the area found 1¼ miles west of Grass Valley.

Composition.—The analysis by Dr. W. F. Hillebrand of an apparently fresh specimen from Kate Hayes Hill, near the Hecla shaft, gave:

Analysis of Grass Valley diorite.

	Per cent.
SiO_2	63.85
TiO_2	.58
Al_2O_3	15.84
Fe_2O_3	1.91
FeO	2.75
MnO	.07
CaO	4.76
SrO	Trace.
BaO	.06
MgO	2.07
K_2O	3.08
Na_2O	3.29
Li_2O	Trace.
H_2O below 110° C	.28
H_2O above 110° C	1.65
FeS_2	.04
P_2O_5	.13
Total	100.36

The comparatively simple composition renders a calculation of this analysis possible, under the well-founded supposition that the hornblende is of the ordinary aluminous character.

		Per cent.
SiO_2	11.6	
Al_2O_3	3.3	
K_2O	3.1	
$KaAlSi_3O_8$		18
SiO_2	19.2	
Al_2O_3	5.5	
Na_2O	3.3	
$NaAlSi_3O_8$ (*a*)		28
SiO_2	5.3	
Al_2O_3	4.4	
CaO	2.4	
$CaAl_2Si_2O_8$ (*b*)		12.1
SiO_2	6.7	
FeO	3.2	
Fe_2O_3		
Al_2O_3	2.6	
MgO	2.1	
CaO	2	
Hornblende		16.6
Quartz		20.8
Magnetite (estimated)		1.5
Titanite		1.4
Apatite		.3
Total		98.7

a and *b* = Ab_7An_3, 40.1 per cent.

The hornblende would then have the following approximate composition:

	Per cent.
SiO_2	40.3
Al_2O_3	15.7
Fe_2O_3	19.3
FeO	
CaO	12.1
MgO	12.6
Total	100

The plagioclase has the composition of an oligoclase, which corresponds with the microscopic investigation.

It is evident that there is considerable variation in the alkalis, for a partial analysis of the rock from Allison's ranch, rather rich in hornblende, by W. H. Melville, gave 6.16 per cent CaO, 0.53 K_2O, 3.74 Na_2O, probably corresponding to 30 per cent Ab, 15 per cent An, and 3 per cent Or, or a normal quartz-diorite.

Weathering.—Though similar to the Nevada City rock in composition and grain, it develops a considerably greater resistance to weathering. It forms light-colored, rounded outcrops, but less characteristic than those of Nevada City; nor does the disintegration extend down so deep by far as in the Nevada City area. The extreme result of weathering is a deep-red clayey soil, a few feet deep.

Relation to surrounding rocks.—While the granodiorite is singularly free from dikes and intrusive masses, dikes of it occur in the surrounding rocks, showing its more recent age. The contacts are satisfactory only at isolated places, on account of extensive weathering, but whenever well exposed are sharp and distinct. On the north the granodiorite borders against the sedimentary rocks with distinct, though not wide, contact-metamorphic zone. A dike-like mass of granodiorite with unsatisfactory exposures is contained in the sedimentary series one-half mile west of the railroad station. The contact with the siliceous chert in the southwest part of the area is very poorly exposed, but does not give the impression of very intense contact metamorphism.

The diabase and porphyrite near the contact are not appreciably altered by the granodiorite, as fresh diabase occurs close up to or immediately at the contact. Dikes of granodiorite in the latter rock were noted at the old Peabody shaft, in Wolf Creek, a little above the Granite Hill mine, in the tunnel 800 feet south of Central North Star shaft, in an outcrop in the swampy meadow 2,300 feet south of North Star shaft, and less well exposed at several points along the contact south of the W. Y. O. D. mine.

APLITE.

Definition.—Aplite is here used to designate granular to fine-granular acid rocks, chiefly consisting of alkali feldspar and quartz, and usually occurring as dikes or dike-like masses in or near the larger bodies of granitic rocks.

Occurrences and description.—A small, 10-inch-wide vein of coarse pegmatite crops out along the road 200 feet north of the Mountaineer mine. On the Excelsior ditch, about 1 mile above Jones Bar and about 4 miles from Nevada City, there is, in granodiorite, a dike 3 to 4 feet wide, of a medium-grained white or yellowish rock, consisting of feldspar and quartz, with a very little brown mica. This rock (220 N. C.) contains 1.06 per cent CaO, 5.57 K_2O, and 3.43 Na_2O, according to a partial analysis by Mr. George Steiger, and is thus a granitic dike rock with predominating alkali feldspars.

In the northwestern part of the Nevada City tract there is, in diorite, a large mass of this rock running out in numerous branching dikes. These little dikes, intruded in the dark amphibolitic rock, are well exposed where Rock Creek crosses the eastern limit of the aplite. The rock is almost white, medium-grained, of a sugary texture, and contains only a few small grains of biotite or hornblende. At the southern end of the area it has a somewhat schistose or pressed appearance. The rocks of this area have been subjected to dynamic action, possibly a direct result of the strains during the formation of the vein fissures, and though schistose structure is not always visible, the microscope reveals its crushed condition. It is essentially a nearly allotriomorphic, interlaced, granular aggregate of quartz and feldspar, except for a few scattered foils of brown mica and grains of epidote. The quartz grains are usually crushed and pressed out to long-drawn aggregates; the feldspar grains show this to a smaller extent. Between the larger feldspar grains there are many small ones, occasionally with micropegmatitic structure, and sometimes giving the impression of having been produced by peripheral crushing. Microperthitic intergrowths are extremely common; there is also some microcline. A few of the grains show distinct twin lamellæ, but some grains otherwise resembling orthoclase have an extremely fine and hardly visible striation in one direction and may be anorthoclase. A partial analysis of No. 159 N. C. by Mr. H. W. Stokes gave 77.05 per cent SiO_2, 0.73 CaO, 5.06 K_2O, and 3.43 Na_2O. The close agreement with the rock from Excelsior ditch should be noted. The aplite dike, 200 feet above the Champion mill, is very similar to the rock just described, though not quite so much pressed.

GRANITE-PORPHYRY.[1]

Definition.—The granite-porphyries are holocrystalline, porphyritic dike rocks, rich in free silica and characterized by the prevalence of alkali feldspars.

Occurrence and description.—Certain rocks occurring as dikes in the diabase near the granodiorite contact, chiefly in the vicinity of the Omaha mine, Grass Valley tract, belong to this group. The sometimes very fine grained groundmass caused them to be laid down on the map as quartz-porphyries; but as they are true dike rocks, closely connected with granitic intrusions, the name "granite-porphyry" is more appropriate. These rocks differ only structurally from the aplites.

The granite-porphyries are chiefly yellowish-gray or gray, fine-grained or flinty rocks, indistinctly porphyritic by small feldspar or quartz crystals ranging up to 3 mm. in size. Small foils of biotite are sometimes present.

Microscopically, several types are present. No. 113 G. V., from the principal area, contains idiomorphic, short and thick feldspar crystals, at least half of them with twin striation. Phenocrysts of clear quartz

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[1] Quartz-porphyry on map.

with corroded outlines are present. White mica and some epidote has formed in the feldspars. The biotite foils are converted into epidote-chlorite aggregates.

The groundmass is microcrystalline, of interlocking grains of quartz and unstriated feldspar; also some with twin striation. In places the groundmass shows micropegmatitic intergrowth, approaching spherulitic forms. Small foils of biotite occur in the groundmass.

A partial analysis by Mr. George Steiger gave—

	Per cent.
SiO_2	75.45
CaO	.69
K_2O	4.56
Na_2O	3.53

or practically equal quantities of Or and Ab.

Another rock from a smaller dike (109 G.V.) is yellowish-gray, fine-grained, but not flinty. Under the microscope it is a spherulitic aggregate of feldspar and quartz, the spherulites ranging from an intimate micropegmatitic intergrowth to typical radial aggregates, showing the black cross between crossed nicols. The groundmass between the spherulites is fine-grained, allotriomorphic, partly also micropegmatitic.

A partial analysis by Mr. George Steiger gave—

	Per cent.
CaO	0.60
K_2O	4.21
Na_2O	3.20

showing this rock to be practically identical with the one first described. SiO_2 was not determined, but the rock is very acid.

A third type, a dike in diabase from the fourteenth level of the Omaha mine, near the shaft, is grayish, flinty, and shows small feldspar crystals. Under the microscope the feldspar phenocrysts are very much filled with micaceous aggregates, clouding them completely. The groundmass is a clear allotriomorphic aggregate of quartz and unstriated feldspar, easily resolved by objective No. 7 (Hartnack).

Similar rocks are also found in the diabase near the contact in the W. Y. O. D. mine. White dikes, either quartz-porphyries or aplites, are those on Little Wolf Creek, 660 feet south-southeast of the Golden Treasure shaft and in the new Peabody shaft. Both of these contain abundant pyrite, possibly introduced by the vein solutions.

DIORITE-PORPHYRITE.

Occurrences and description.—The granodiorite being the latest principal member of the fundamental series, very few dikes of any kind are found in it. The aplites have already been mentioned, and the granite-porphyries in all probability are also later, though not found in the granodiorite. In three places basic dark-green porphyritic rocks have also been found as dikes in granodiorite. There may be more occurrences of the same rock as dikes in other parts of the fundamental series, but if not prominent they would easily be overlooked, as they present great similarity to the ordinary hornblende-porphyrites.

The best exposure, to which Mr. George A. Treadwell called my attention, is in the canyon of the South Yuba River, 800 feet below the Excelsior dam, about northwest of Nevada City and 2 miles outside of the special sheets. At this place there are two dikes 16 inches wide in the normal granodiorite, only a few feet apart; both dip 30° W., and many fissures and joints with the same dip are seen in the vicinity. The rock is dark-green and dense, with many small feldspar crystals and abundant acicular black hornblende. In thin section the rock is seen to be holocrystalline porphyritic; the larger feldspar crystals are not over 1 mm. long, while the needle-shaped hornblende may reach 2 or 3 mm. The former are sharply idiomorphic and show twin striation; the latter pale greenish-brown in color and with normal extinction. The groundmass is composed of microlites and grains of the same hornblende, and apparently also the same plagioclase, as there are all transitions between the phenocrysts and the microlites in the groundmass. Magnetite is rather abundant. According to a determination by Mr. George Steiger, the rock contains 60.85 per cent SiO_2. The rock shows plainly the character of the lamprophyric dike rocks, and is closely related to the camptonites, though not so basic. Such dike rocks have been found, though not abundantly, in various parts of the Sierra Nevada, and are apparently always later than the granodiorite.[1] They often appear parallel to the gold-quartz veins, and have evidently been injected a short time previous to the formation of the latter. Two localities have been found in the Banner Hill tract, but in both cases the rocks are so altered as to be scarcely recognizable. The first is a dark grayish-green rock found on the dump of the Independence shaft (Murchie mine), and is said to have come from a dike running parallel to the vein, which dips W. 36°. In thin section it is seen to be a very much altered porphyritic rock, with long, slender hornblende needles, now entirely converted to calcite. The second occurrence forms a 3-foot-wide dike in the Alpine tunnel, forming the hanging of the St. Louis vein. The rock has much the same extremely decomposed appearance as that from the former locality, and shows small hornblende prisms in a groundmass of fine felted mixture of feldspar microlites and acicular hornblende.

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[1] Compare The gold-silver veins of Ophir, Cal.: Fourteenth Ann. Rept. U. S. Geol. Survey, p. 262.

THE DIORITE-GABBRO-PERIDOTITE GROUP.

The rocks of this series, embracing diorite, gabbro, hornblende rock, pyroxenite, peridotite, and serpentine, form a series so intimately connected by transitions that there can be no doubt of its close genetic relationship; nor is it possible to strictly separate the rocks in the description.

DEFINITIONS.

Under *diorites* are here included the coarse-granular, abyssal rocks with normal granitic structure, composed chiefly of soda-lime feldspars of medium acidity and hornblende; biotite or pyroxene may sometimes replace the hornblende. The granodiorites, an intermediate group ranging from quartz-diorite to quartz-monzonite (Brögger), have already been separated. With the granodiorite has been included several smaller masses and dikes, which probably are only local products of differentiation of the granodiorite magma. The diorites have a silica percentage varying between 51 per cent and 58 per cent. The lime is considerably in excess of the sum of the alkalis, the reverse being true of the granodiorites. A considerable percentage of ferromagnesian silicates is usually present.

The *gabbros*, as here defined, include similar rocks with basic feldspars (labradorite or anorthite); the ferromagnesian silicates may be either pyroxene, hornblende, or mica.

The *pyroxenites* are coarse-granular, very basic rocks of granitic structure composed chiefly of pyroxene, with very small amounts of feldspar.

The *peridotites* are similar rocks composed of olivine and a pyroxene or an amphibole.

The *serpentines* are secondary rocks, consisting chiefly of serpentine, with minor quantities of residuary minerals or newly formed actinolite. They are evidently derived from gabbros, pyroxenites, and peridotites, chiefly from the latter two. It will be shown later that they may also be derived from certain porphyrites. The action producing the serpentines is not weathering, but must be regarded as similar to the actions effecting metamorphic alterations.

Referring to the Smartsville folio, it will be seen that a double wedge-shaped area, determined as gabbro-diorite with masses of pyroxenite, peridotite, and serpentine, extends from Birchville to a point east of Grass Valley, adjoining the granodiorite and diabase on the east and the diabase and sedimentary rocks on the west. The name *gabbro-diorite* was adopted as a convenient expression to include different rocks belonging to the diorite and the gabbro families. It would no doubt have been better to designate this mixture of rocks gabbro *and* diorite. The area is one of great complexity, with gradual transitions between the gabbros, diorites, and pyroxenites, while the serpentines are more sharply defined. In the northern part of the large area great complexity is added by the fact that the whole has been subjected to more or less intense dynamometamorphism. Several parts of this area fall within the space of the detailed sheets.

THE ORO FINO DIORITE-PYROXENITE AREA.

Reference has already been made to this area in the northwest part of the Nevada City tract while discussing its indistinct contact with the granodiorite.

The southern part of the area, running out in the shape of a wedge, contains chiefly diorites of dark color and average granular texture, weathering less easily than the granodiorite, forming rougher outcrops and a scant, deep-red soil.

Under the microscope the rocks are shown to be diorites with very little biotite and a little quartz, the latter often included in the hornblende. There is very little pyrite in the rock. Near the Kirkham mine the diorite contains many small pegmatite veins.

At the northwestern end of the big aplite dike the rock has changed to a dark-green, coarse-granular pyroxenite, consisting chiefly of large irregular grains of a partly uralitized pyroxene (diallage?), with some grains of apparently primary greenish-brown hornblende with augite kernels. Between the pyroxene grains lie small grains of a feldspar, largely converted into micaceous aggregates.

Small dikes of aplitic rocks are found in the pyroxenite. In other places close by (800 feet northwest of Coan's mine) there is a larger amount of anorthite with broad twin lamellæ and appropriate extinctions; consequently the rock is here a gabbro.

Still farther north, 2,400 feet north of Coan's mine, the coarse-grained, dark rock consists of partly uralitized augite, greenish-brown hornblende, biotite, and triclinic feldspar, with a little quartz and probably also some orthoclase. There is also magnetite (ilmenite?) and much apatite.

Still farther northwest, at the Oro Fino mine, dark, coarse-granular rocks appear which are intermediate between diorite and gabbro. The specimen, from the dump of the mine, is somewhat decomposed and affected by pressure, many of the feldspar lamellæ being curved and bent. It consists of an apparently not very basic plagioclase, augite, and biotite; probably also some orthoclase and quartz.

THE PLEASANT FLAT DIORITE AREA.

Description of rock.—This area, extending on both sides of Deer Creek, at the western limit of the special map is predominantly composed of a fairly normal diorite of coarse texture and dark-green color, containing a large amount of hornblende. Seen in thin section, the hornblende is brownish-green, partly anhedral, partly roughly prismatic; the feldspar is lath-shaped or anhedral with twin lamellæ, the extinctions of which indicate a medium basicity. A little quartz is sometimes found between the grains. The sericitic alteration has proceeded far, as a rule; much of the hornblende is also converted to uralite, chlorite, and epidote. On the whole, there is much more of these secondary minerals than in the granodiorite. Grains of pyrite are scarce and usually associated with epidote; in some cases they might possibly be primary.

A partial analysis of a typical specimen, by Dr. Peter Fireman, gave:

	Per cent.
SiO_2	51.24
CaO	7.97
K_2O	.93
Na_2O	3.44

Of the CaO, at least 2 per cent, probably 3 per cent, must be contained in the hornblende. (Compare calculation of Grass Valley granodiorite.) There would thus be not more than 30 per cent An and 27 per cent Ab, which shows that the feldspars are only of medium basicity.

Facies of the rock.—In many places the rock is subject to changes in grain and composition, some parts of it being richer in hornblende, while in some parts the feldspar acquires more prominence and some quartz begins to appear. At Carls tunnel, near the andesite contact, the rock on the dump exhibits a very coarse pegmatitic structure, and consists of uralite crystals several inches long in a white, partly saussuritic mass, with sp. gr. 2.98. To the northward, beyond the special maps, the rock gradually changes to a typical light-colored gabbro, and even in this area there is undoubtedly a certain relationship with the gabbro occasionally exhibited.

Weathering.—Deep, rich, residual soil produced by weathering occurs south of Deer Creek, and especially near the andesite contact. On the north side the soil is less deep, but the rock is disintegrated and crumbling.

Relation to surrounding rocks.—Toward the north and east the diorite is in contact with serpentine and peridotite, with a rather sharply defined contact. Tongues of serpentine extend into the diorite, as shown on the map. The area contains an extensive system of dikes of uralite-diabase, which will be described later.

THE FAIR-GROUND AREA OF DIORITE.

Description.—This is really the continuation of the above-described area, emerging from below the southern edge of the covering andesitic tuff. The character of the rock is also entirely similar, being a coarse, dark diorite. There is in some places also the same frequent and rapid change of grain and basicity. The rock is deeply decomposed on the hill northwest of the Fair-grounds.

Relation to other rocks.—Toward the northeast the contact with the dark-green porphyrites is in places very indefinite and not well exposed, much apparently brecciated material occurring along it. The coarse diorite contains fragments of darker greenstones of finer grain. Along the north side of the race-track there is a considerable amount of this mixed material. The contact with the serpentine is fairly sharp.

DIORITE AREAS IN THE SERPENTINE.

Smaller masses of diorite, irregular or lens shaped, occur in the serpentine. The largest one, north of the Idaho mine, is substantially like the Fair-ground area, and contains besides some dikes of a hornblendic porphyrite.

In the Indian Flat serpentine area irregular masses of diorite are frequent, and probably represent dioritic variations of the prevailing peridotite-pyroxenite magma. In the extension of the Idaho serpentine area northwest beyond the special sheets, on the Newtown road, smaller masses of dark-green, coarse-granular *hornblende rock* is found, evidently corresponding to the pyroxenites, and consisting almost exclusively of primary, deep brownish-green hornblende with strong pleochroism. No larger areas of this hornblende rock are found. It should not be confounded with the amphibolites, which, as here defined, include only the dynamo-metamorphic rocks in which the hornblende is secondary.

THE MOREHOUSE DIORITE DIKE.

This dike-like body is contained in serpentine and gabbro half a mile west of the Maryland mine. It is a medium-grained, grayish-green rock, containing, besides feldspar and hornblende, much pyrrhotite in small grains. Under the microscope the rock consists of the usual dioritic hornblende in irregular grains, lath-like or irregular feldspar with narrow striations, with smaller residual masses of orthoclase and quartz and a little magnetite. The structure is typically hypidiomorphic. There is much chlorite with the hornblende, and micaceous products with the feldspar. The pyrrhotite is generally of secondary origin, occurring chiefly with the chlorite.

GABBRO AREAS.

General features.—Typical gabbros do not form extensive areas in this vicinity; most of the areas occurring as elongated masses in the serpentine probably represent, as does the diorite in similar occurrence, facies of the prevailing pyroxenic or peridotic mother rock of the serpentine.

Gabbro dikes below the Providence mine.—In the dike-like masses on both sides of the serpentine below the Providence mine the gabbro is very coarse grained, consisting of uralitic pyroxene of light-green color and whitish feldspar, very often with a tinge of brown. The grains average about 5 mm. In weathering, the large outcrops assume a whitish color. Microscopically, the feldspars show large anhedral grains with broad striation, the striations indicating a composition between bytownite and anorthite. The diallage is almost wholly converted into uralite, fibers of which are also found in the feldspars. The latter are in part clouded by micaceous products. Some ilmenite is also present, as well as some finely distributed pyrite, the latter probably secondary.

Gabbro in the Maryland serpentine.—There are several smaller areas of gabbro in the Maryland serpentine, one of which is indicated on the map. The rock is only in part typical, some of it being schistose and dynamo-metamorphosed. Up toward Jones Bar, in the continuation of the diorite-gabbro series of the special sheets, there are large areas of gabbro similar to the one here described and also characterized by the whitish color of the outcrops; it is here frequently dynamo-metamorphosed, producing light-colored actinolite schists, often also with much zoisite.

The Maryland gabbro.—The Maryland gabbro area is the largest one found on the area of the special sheets, extending from South Wolf Creek up to the Maryland mine. The rock is in the main similar to the one just described; it is coarse-grained, of a prevailing light-green color, and is composed of uralite-diallage and a basic plagioclase.

The exposures are very poor, the deep disintegration of the rock rendering it difficult to decide the relations with the surrounding rock. It borders, with a fairly distinct contact, on the serpentine, smaller masses and seams of the latter rock occurring in the gabbro. Toward the east the contact with the coarser diabases of the Maryland area is very obscure; abundant dikes of diabase, extending from the main area, appear to be contained in the gabbro, but in the area laid down as diabase there is also, as at South Idaho, more or less gabbro traversed by dikes of the darker rock. The best exposures are along the railroad near the sulphuret works, but they are very unsatisfactory; the gabbro disintegrates easily to a crumbling mass, while the hard diabase dikes remain intact, their fragments covering the ground.

The East Maryland gabbro.—Half a mile east of the Maryland mine another gabbro area begins. This is practically included in serpentine, and the rock varies a great deal in composition. While the prevailing rock is the normal, coarse, whitish gabbro, there is also much of darker diabasic and amphibolitic rocks, the relation of which to the gabbro is obscure on account of poor exposures. On the dump of the Chevannes tunnel much saussurite or saussuritic gabbro was found.

A little gabbro is also found in the Mariposa slates at the south end of the small serpentine area near the Washington mine (6,500 feet east of the Maryland mine).

THE INDIAN FLAT SERPENTINE AREA.

Extent.—Beginning under the andesite northwest of Town Talk, this area extends beyond the limits of the map to a point some distance northwest of the Yellow Diamond mine.

Description of rocks.—The serpentine in this area is only partly a pure rock and usually bears clear evidence of its derivation from pyroxenites and peridotites, in part probably also from gabbro. The residual masses of gabbro and diorite occurring in it have already been mentioned. In its northwestern point unaltered pyroxenites appear, while good peridotites are exposed where the Newtown road crosses its western contact.

While there is some of the pure light-green serpentine with glistening curved faces of the fragments, the prevailing rock is a black to dark-brown or dark-green dense rock, rather soft and with dull surface, in places showing, however, a peculiar satiny luster. Occasionally, as, for instance, in the rock from the old tunnel 2,300 feet south of the Wyoming mill (116 N. C.), the serpentine of the appearance just referred to is fairly pure and shows a grate structure by development of more sharply bi-refracting fibers crossing each other at varying angles. There are, further, some tremolite or actinolite, a little talc, and abundant irregularly distributed magnetite, and, lastly, clouded and corroded remains of a pyroxene mineral.

A specimen from the north side of Deer Creek, 2,500 feet west-southwest of the Providence mine (131 N. C.), is a black, apparently fine-grained rock with a satiny luster. The microscope shows it to be a very imperfect serpentine. There is a large quantity of clouded residual pyroxene, probably enstatite, traversed in all directions by radiating or crossing fibers of serpentine with gray colors of interference. The olivine is not so easily recognized, but is probably also present. Some secondary actinolite in radiating fibers traverses the pyroxene; aggregates of talc are also noted. The magnetite is abundant, anhedral or in sharp crystals, and arranged to form an incipient net structure, best seen in reflected light. Pyrite also occurs in this rock, in anhedral grains closely associated with magnetite.

A serpentinoid rock of similar appearance from near the contact north of Pleasant Flat shows remains of pyroxene and olivine; the serpentine traverses the original minerals in net-like veins composed of a very cryptocrystalline, clear mass. Talc and actinolite are present, as usual. It should be noted, however, that it is impossible to distinguish fine micaceous aggregates from talc, and if feldspar was present in the original rock white micas might be expected in the resulting serpentine.

Weathering.—This impure serpentine derived from pyroxenite and peridotite is very resistant to surface decomposition. It forms reddish-brown, rough outcrops, with practically no residual soil. West of Indian Flat a probably thermal alteration has produced a large mass of brown or white, cellular, chalcedonic rock. Moss agates, so called, consisting of translucent chalcedonite with black dendritic inclusions, have been obtained from this locality.

Relation to surrounding rocks.—The contact with the amphibolites on the east is distinct, though insufficient exposures do not permit a satisfactory establishment of the relation between the rocks. The contact on the west with the wedge-like projecting serpentine masses has already been referred to.

THE TOWN TALK SERPENTINE AREA.

This small area, 1,500 feet long and only a few hundred feet wide, is in character of rock similar to the larger mass just described. Residual pyroxene, and occasionally olivine, is contained in the serpentine, as well as secondary actinolite. One specimen with dense, dark-green, flinty appearance is a mixture of serpentine, chlorite, and actinolite. On account of unsatisfactory outcrop, nothing definite can be said about its relation to surrounding rocks; it lies as a dike-like mass between dark-green porphyrites on the west and black clay-slates on the east.

A similar small area with some gabbro at its southern end is found north of the Washington mine, southeast of the Town Talk area.

THE MARYLAND SERPENTINE AREA.

Extent.—Beginning as a narrow wedge in gabbro northeast of Newtown and flanked by smaller masses of peridotite and pyroxenite, this large serpentine area enters the special sheets west of the Fair-ground, and between the Maryland mine and Grass Valley sends out a long wedge-shaped mass southward toward the sulphuret works. Continuing southeast, the area runs out to points again; near the Brunswick mine two branches are separated by a mass of gabbro.

Description.—The rock is a normal serpentine of dull dark-green, dark-brown, or black color, sometimes containing veins of chrysotile; a light-green crushed serpentine, breaking in smooth, glistening fragments, is also found in places. Masses of diorite and gabbro are not abundant in it.

The rock in this area is much more normal than is the Indian Flat serpentine. In most of the specimens examined the serpentinization is complete, no remains of the original minerals being found. The structure is, as a rule, an imperfect grate structure, by the development of stronger bi-refracting fibers crossing one another at varying angles; between the fibers lies less strongly bi-refracting serpentine with undulous extinction. A little talc and actinolite occurs, but far less than in the Indian Flat area. There is abundant magnetite, sometimes arranged so as to form a net structure; a dark-brown, translucent chromite is also noted in some specimens. Finely disseminated pyrite was found in the serpentine 1,700 feet west of the Eureka shaft embedded in fresh serpentine and in chrysotile veins; it is closely associated with the magnetite and sometimes included in it; in one place a cluster of small yellow needles was noted, possibly millerite or sulphide of nickel· The presence of some calcite in the rock renders it possible, however, that some of the pyrite may be due to the vein solutions.

North of the areas of the special sheets remains of pyroxene and olivine are more frequently found in the serpentine.

Weathering.—The rock weathers very much like that of the Indian Flat area, in rough, reddish-brown outcrops; the rocky serpentine hills are almost bare of any residual soil, and are characterized by a scrubby growth of digger-pine and thorny brush (Ceanothus).

Relation to surrounding rocks.—The contacts of the serpentine with the sedimentary rocks, as well as with diabase and porphyrite and with the gabbro and diorite, are fairly sharp; least so, probably, the gabbro contacts, but the decomposition of the rocks renders it difficult to obtain distinct evidence as to succession. The relations at the St. John shaft are shown in the diagram accompanying the description of that mine. Small bodies of serpentine are occasionally found in the diabase, as at the reservoir 1,000 feet southeast of the Maryland mine. Numerous dikes of diabase and porphyrite are found in this serpentine area, and will be discussed later.

THE CROWN POINT SERPENTINE AREAS.

At the Crown Point mine and northwest of it there occurs in the sedimentary rocks dike-like masses of serpentine in close connection with certain basic porphyrites, to be described later. The relation of the serpentine and porphyrite is very similar to that indicated in the St. John section, and the inference is scarcely to be avoided that the latter rock is subject to a serpentinization. Specimens from the New Eureka prospect shaft and from near the Crown Point show the presence of much actinolite and some chlorite in the serpentine. There is also some chromite. The rock from the latter locality (bridge by Crown Point mill, 116 G. V.) is not exactly like a normal serpentine, being dark-green, hard, and showing somewhat splintery fracture. Residual pyroxene was noted in this rock.

CHAPTER IV.

THE IGNEOUS ROCKS OF THE BED-ROCK SERIES—(CONT'D).

THE DIABASE AND PORPHYRITE GROUP.

DEFINITIONS AND GENERAL FEATURES.

Under diabase are here included hypidiomorphic granular rocks composed chiefly of a soda-lime feldspar with augite; hornblende may partly or even wholly replace the augite. The texture ranges from coarse to rather fine grained, the latter forming transitions to the porphyrite group. The typical structure distinguishing it from the gabbros is "diabasic granular" or "ophitic," characterized by long, lath-shaped feldspars, the interstices being filled by the augite. Through a more granular development of the feldspars frequent transitions to dioritic structure are effected. It was proposed to restrict the term "diabase" to those rocks carrying basic feldspars (labradorite to anorthite), but this has not proved feasible without creating too artificial distinctions.

Under diabase-porphyrite are included the finer-grained forms of diabase in which are contained phenocrysts, usually of feldspar, thus giving the rock a porphyritic habit.

Under augite-porphyrite and hornblende-porphyrite are here included the pre-Tertiary porphyritic rocks, consisting chiefly of soda-lime feldspar and augite, hornblende, or biotite. The structure is porphyritic by phenocrysts of any of these constituents. The groundmass is chiefly feldspathic, ranging from cryptocrystalline to microcrystalline; very common is a pilotaxitic structure forming a transition to the diabase-porphyrites. In these porphyrites the feldspar is, as a rule, somewhat less basic than in the diabases. No glass has been detected, but remains of it might well have been devitrified and thus escaped attention. The porphyrites are probably chiefly effusive rocks; but may also occur as intrusive bodies.

Rocks belonging to this group have a wide distribution in the areas covered by the special maps. They are in general dark-green, rather basic rocks of medium to fine granular or holocrystalline porphyritic development, augite prevailing among the ferromagnesian silicates, though hornblende also occurs. Collectively they would formerly have been referred to as "greenstones." They range in composition from normal diabases, with from 47 to 53 per cent SiO_2 and rich in lime, to quartz-porphyrites of a composition similar to that of many granodiorites; the latter division is in general segregated from the rest and separately indicated. From the normal diabases there are gradations into hornblende-diabases and into augite-plagioclase rocks with a more eu-granitic structure. Again, the diabase may readily become porphyritic, the resulting rock being referred to as diabase-porphyrite. A more pronounced porphyritic structure with finer-grained holocrystalline groundmass gradually leads over into the porphyrites, referred to as augite-porphyrites or hornblende-porphyrites. Besides these main divisions there are others less prominently represented, such as fourchites (J. F. Williams), or porphyritic rocks consisting chiefly of pyroxene, and augite-syenite, the latter probably only a facies of the diabase. There are further great masses of old tuffs and contact breccias among this group.

In face of such a variety of rocks, gradually changing in composition and structure and still by necessity to be regarded as a geological unit, the limitations of petrographical classification become painfully apparent. It can not be regarded as proved that the different areas occupied by this series are of exactly the same age, but the probability appears great that the time of eruption of all these rocks falls within moderate limits. They are much later than the Calaveras formation, being partly contemporaneous with, partly slightly later than, the Mariposa beds. Granodiorite appears to be the only principal rock which is decidedly later than the diabase-porphyrite series.

The frequent porphyritic character, and especially the abundant presence of fragmental rocks, characterize the group, in contrast to the granodiorite and the diorite-gabbro group, as surface eruptions, while the transition in granular diabases, on the other hand, tends to connect it with the intrusive rocks. It is probable that the group represents what is left of the extensive volcanoes which at the close of the Jurassic period were built up along the foothills of the Sierra Nevada. The erosion having removed the upper part, the remaining cores are exposed. The progressive eruptions of new material as the volcanic masses piled up will to some extent explain the close juxtaposition of rocks of intrusive and effusive types. Professor Iddings's descriptions of the Electric Peak rocks offer many analogies to the phenomena here presented. It may not be amiss to call attention to the fact that the rocks most resembling the effusive types of modern andesites are found about Banner Hill, in the highest parts of the area, but no distinct law governing the distribution of the different structures can be formulated.

Finally, this group has been extensively subjected to metamorphism, developing uralite, epidote, chlorite, pyrite, and other minerals, and sometimes converting the rock into amphibolitic schists.

A majority of these porphyrites are, strictly speaking, the somewhat altered and perhaps partly devitrified equivalents of the modern andesites, and might be called "apo-andesites," according to a recently suggested nomenclature.

This or a similar classification has not been adopted because it was believed that great confusion would result. The gap existing between the Tertiary andesites and the Mesozoic porphyrites is, in the Sierra Nevada, very wide and marked.

THE DIKES IN THE FEDERAL LOAN ARGILLITES.

General features.—Very many dikes are contained in the partly contact-metamorphosed rocks of this area, but most of them are of small extent and irregular form and can be traced only for short distances. It is rarely possible to trace them with great accuracy under the deep covering of residual soil; the impression of great extent gained by the abundant fragments is corrected by inspection of fresh exposures, as along the canyon of Deer Creek. Although occurring abundantly close up to the granodiorite, none have been found in that rock. They usually contain a considerable quantity of sulphides, as do the argillites in which they are contained, and also, as the argillites, secondary biotite.

Fourchite.—The fourchites, according to J. F. Williams,[1] are characterized as porphyritic rocks with phenocrysts of augite in a prevailingly augitic groundmass. Rocks of this character, really the porphyritic equivalent of pyroxenite, occur in this area at two places—as a small dike a few feet wide at the foot bridge 500 feet northwest of the Federal Loan mine (52 N. C.), and as a larger dike at the andesite dike north of Willow Valley Creek. The latter is adjoined southward by another dike of quartz-porphyritic character. The dark-green rocks carry augite crystals, colorless in thin section, green in specimen, several millimeters large, of stout prismatic habit, partly uralitized and showing peculiar twinning, sometimes with polysynthetic lamellæ, probably parallel to a dome or a pyramid. The groundmass is chiefly a fine aggregate of small prismatic or anhedral uralite grains with a little sericitized feldspar.

Diorite.—A dike-like mass of dioritic rock occurs on the divide between Scotts Flat and Willow Valley, at the road to the former place. It is a dark-green, medium-grained rock, consisting of roughly idiomorphic, brown, partly bleached hornblende, lath-shaped plagioclase and a little orthoclase, the latter cementing the plagioclase prisms; very abundant titanite and pyrrhotite, the latter possibly primary in part; much chlorite and epidote. Though a diorite, the rock is believed to to be closely related, geologically, to the diabase eruptions.

Porphyrite.—Dikes of this character are most frequent, and the rocks may be classed either as hornblende-porphyrites or quartz-hornblende-porphyrites. They are in general dense, dark-gray rocks, with a tinge of green or brown, with phenocrysts of hornblende, in some cases up to 2 cm., but usually 1 to 3 mm., in length. The feldspar phenocrysts are less conspicuous. Under the microscope the hornblende, while more or less uralitic, bears evidence of having been originally of dark-brown color; maximum extinction, 20°. The feldspar phenocrysts are well defined, but usually obscured by sericitic and epidotic aggregates. The holocrystalline groundmass is, in the quartzose porphyrites, of a fine-grained, allotriomorphic character, while in the quartz-free rocks it

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[1] Arkansas Geol. Survey, 1890, Vol. II.

readily assumes a pilotaxitic structure by the microlitic development of the feldspars. The groundmass is prevailingly composed of feldspar, though in the quartz-free porphyrites there are also small prisms of uralitic hornblende. Many of the rocks contain finely disseminated, reddish-brown biotite in the groundmass and in the uralite crystals; this biotite is probably not primary, but has been developed by metamorphic processes. It can scarcely be due to contact metamorphism, for the granitic contact is for many of the occurrences several thousand feet distant. A similar development of brown mica will be shown in the metamorphosed diabases of the Nevada City area. Magnetite is abundant, as is pyrite, and especially pyrrhotite. In part these sulphides are doubtless secondary, but in other sections (32 N. C.), where intimately intergrown pyrite and magnetite fills many of the hornblende crystals, a primary origin suggests itself strongly. Chlorite, epidote, and sericite are abundant. On the whole, the rocks may be characterized as greatly altered, though no mechanical effects of dynamometamorphism are visible. Specimen 22 N. C., from near the edge of the Banner Hill area, 200 feet south of the Scotts Flat road, was analyzed. It is a dark-gray, fairly fresh rock, porphyritic by black hornblende crystals of prismatic habit, about 3 mm. long; the feldspar phenocrysts are small and not prominent. The groundmass is dense, grayish-brown, with splintery fracture. Under the microscope the hornblende is greenish-brown, and shows sharp idiomorphic outlines. The feldspars are filled by epidote and a sericitic mineral. The groundmass is a very fine grained, allotriomorphic, feldspar-quartz aggregate, with a great development of small chestnut-brown biotite foils.

The following analysis of this rock was made by Dr. H. N. Stokes:

	Per cent.
SiO_2	62.09
TiO_2	.32
P_2O_5	.39
SO_3	.10
Al_2O_3	16.69
Fe_2O_3	1.45
FeO	3.76
MnO	Trace.
BaO	.10
CaO	6.08
MgO	1.93
K_2O	1.84
Na_2O	3.36
H_2O below 110° C	.19
H_2O above 110° C	1.47
	99.77

The chemical composition of this rock approaches very closely that of some granodiorites. Making due allowance for the CaO contained in the hornblende, there is evidently more Ab than An, and, besides, not so little orthoclase.

THE BANNER HILL DIABASE AND PORPHYRITE AREA.

Extent.—As shown by the general map (Pl. I), this area is entirely surrounded by sedimentary rocks of the Calaveras formation. The part of it shown in the southeast corner of the Banner Hill sheet is of almost bewildering complexity. Were the exposures better it might be possible to further subdivide the area. It is, however, unquestionably a geological unit, and according to the best evidence available the rock types are closely connected by transitions. The occurrence of brown hornblende characterizes most of the rocks in this area.

Description of rocks.—As no general description can be given, it is necessary to single out principal types. No. 71 N. C. (Banner Hill bears N. 20° W., and is 4,700 feet distant) shows in a grayish-green groundmass white feldspar crystals up to 1 mm. long, and stout, prismatic, black hornblende up to 10 mm. in length. Under the microscope the idiomorphic brown hornblende, with extinctions about 20°, shows peculiarly rounded or corroded outlines; some stout, partly uralitized augite crystals are also present. The idiomorphic feldspars are largely converted to epidote and micaceous minerals. Grains of ilmenite or titaniferous iron ore partly converted to titanite are rather abundant. The groundmass is apparently holocrystalline and consists chiefly of small feldspar microlites mixed with small grains of uralite and chlorite. The rock is a typical hornblende-augite-porphyrite.

A specimen from the lower Quaker Hill road near the edge of the map (57 N. C.) is dark-gray in color with a brownish tinge, and indistinctly porphyritic by small feldspar and augite prisms. It contains abundant pyrrhotite. In thin section the colorless, prettily idiomorphic augites are partly uralitized, the feldspars being completely decomposed to epidote, micaceous aggregates, and cloudy masses, probably kaolinite. The groundmass is holocrystalline and consists of medium-sized feldspar microlites, with uralite grains, chlorite, and a little dirty-brown biotite; there is very little magnetite, but pyrrhotite is extremely abundant and apparently of secondary origin. In structure this rock stands between a diabase-porphyrite and an augite-porphyrite.

The rock from the extreme southeast corner of the Banner Hill area is a very decomposed, fine-grained, but otherwise normal diabase.

A specimen taken at a place where Banner Hill bears N. 36° W. and is 4,500 feet distant, is a dark-green, coarse, granular rock composed of large (up to 5 mm. in diameter) augite crystals and grains, light-green in color and surrounded by a rim of black hornblende. Between the augites lies finer-grained white feldspar. The microscope shows large grains and imperfect crystals, often-twinned, of clear, and colorless augite, usually surrounded by a border richer in inclusions, chiefly small fragments of brown hornblende; this again is surrounded by an outer rim of clear brown hornblende, bearing every evidence of being a primary constituent. There are grains of magnetite or ilmenite in the hornblende, and also much leucoxene. Pyrite occurs occasionally, with chlorite or intergrown with magnetite. The plagioclase is related to labradorite and occurs in smaller, sharply lath-shaped crystals between the large augites; it is frequently included in the hornblende, more rarely in the augite. Between the laths lies brown hornblende, more rarely augite, occasionally also quartz. A little chlorite, epidote, and uralite occur in the rock. The structure of the rock is distinctly diabasic.

Still another rock, occurring on the Quaker Hill road near the eastern limit of the special sheet, is a medium-grained hornblende-diabase. Both the brown hornblende and the feldspars are partly idiomorphic, though sometimes the latter determines the outlines of the former. This rock is extremely rich in probably secondary pyrrhotite.

Composition.—No analyses of these rocks have been made. On the whole the composition is doubtless that of a diabase, though the porphyrites may be somewhat more acid. Quartz-porphyrites do not appear to occur here.

Weathering.—The rock weathers to a deep, reddish-brown soil of clayey character. The disintegration of the rock has, however, not attained any depth approaching that of the granodiorites.

Relation to other rocks.—On the northwest the area borders against the argillites of Banner Hill, and the contact is of a complicated character, a zone of contact-breccia half a mile wide separating the two formations. There are, in fact, no distinct contacts. The massive rocks gradually change to a porphyrite-breccia of generally small, brown or greenish, firmly welded, angular fragments of hornblende- and augite-porphyrites, with from cryptocrystalline to pilotaxitic groundmass; the feldspars are usually exceedingly altered and uralitic aggregates are common. Besides, the breccia contains more or less numerous sharp, gray to brownish fragments of siliceous argillite, often of the appearance of hornfels. This breccia is characterized by containing a very large amount of pyrrhotite and a little pyrite, while magnetite generally is absent. The pyrrhotite appears to be, largely at least, secondary and due to metamorphic processes.

Northwesterly over the summit of Banner Hill the sedimentary fragments increase, entirely predominating in the breccia, which then finally grades into unbroken argillite.

THE PITTSBURG DIABASE AND PORPHYRITE AREA.

Extent.—Beginning in the southwest corner of the Banner Hill tract and extending diagonally across the Nevada City tract, is a large area of rocks of dark-green color and diabasic or porphyritic character.

Separated by the Mariposa slates, a part of it extends north of the Fair-ground, and, appearing again on the north side of the andesite hill, continues as a narrow dike-like mass in the diorite of Pleasant Flat. The northwestern part of the main area is very much altered by metamorphic processes, which indeed to some extent have affected the whole mass and must be described separately.

Description of rocks.—Going up the northern branch of Wolf Creek, above the Washington mine, one meets with a great variety of coarser diabases and hornblende-diabases with finer-grained hornblende-porphyrites. In the southwest corner of the Banner Hill tract the hornblende-porphyrites prevail. A specimen of these, taken at Thomas ranch (89 N. C.), carries in a dark brownish-gray groundmass feldspar crystals 1 to 2 mm. long and larger black hornblende needles.

Under the microscope the porphyritic feldspars appear very much altered into micaceous aggregates. The brown idiomorphic hornblende is partly converted to green uralite with slightly smaller extinction. The groundmass is pilotaxitic, chiefly feldspathic, and shows flow structure around the phenocrysts. Small foils of brown mica, also a little chlorite and uralite, occur in the groundmass. Pyrite is rather plentiful, often intergrown with magnetite. Both magnetite and pyrite occur as grains in apparently fresh hornblende.

This rock was partly analyzed by Dr. H. N. Stokes, with the following result:

	Per cent.
SiO_2	59.17
CaO	6.66
K_2O	.88
Na_2O	3.4

These figures would indicate a rock with some quartz and a soda-lime feldspar approaching andesine.

Along the crest of the ridge and about Herring's reservoir the rocks are, as a rule, fine-grained to dense, and of dark-green to dark brownish-green color. The microscope shows them to be tuffs of augite- and hornblende-porphyrites containing small fragments of these rocks, larger anhedral grains of augite or feldspar, and some fragments of sedimentary rocks. About the Pittsburg mine and from there on northwestward, greatly altered, dark-green, medium-grained diabasic rocks prevail. The augite, nearly always more or less uralitized, is very prominent and occurs as anhedral or roughly idiomorphic grains which often show a tendency to become porphyritic. Where, besides this, the quantity of augite is great, transitions to the fourchites are formed; such are the rocks in Wood's Ravine, 1,200 feet below the Nevada City mill, and on Gold Flat, 300 feet west of East Orleans tunnel. The feldspar, nearly always greatly decomposed, is in part lath-like, in part more anhedral, the widespread alteration making it difficult to obtain good determinations; on the whole the structure is only partly normal diabasic, and shows approximation to the dioritic.

Augite- and hornblende-porphyrites are also present in this area, as, for instance, north of the Fair-ground. Here the grayish-brown or greenish porphyrites contain small feldspar crystals and hornblende needles 3 mm. long in a groundmass composed chiefly of laths and short prisms of plagioclase, probably labradorite. Another rock in the same vicinity is an altered augite-porphyrite with phenocrysts of plagioclase and pyroxene in a groundmass of micropoikilitic structure characterized by microlites and grains of feldspar in larger quartz grains. This structure is very unusual.

The best exposures are found at the tunnel on the south side of Deer Creek, 900 feet below the Home mine, where the contact with the Mariposa slates happens to be laid bare in the bed of the creek. Fig. 1 illustrates the exposures and affords a key to the whole complex series.

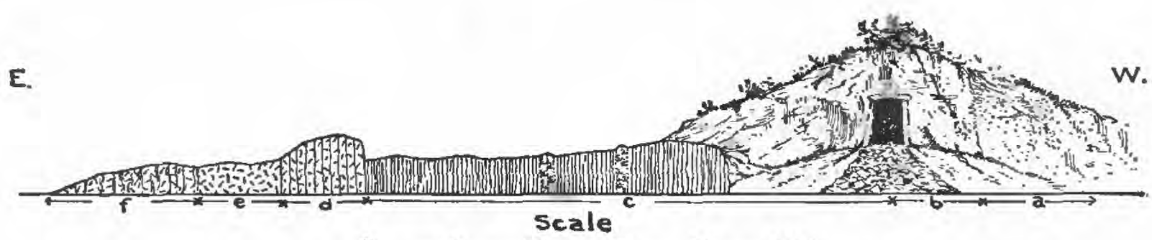

FIG. 1.—Section at tunnel 900 feet below Home mine, south side of Deer Creek. *a*, gabbro; *b*, serpentine; *c*, black mariposa clay-slate with tuffaceous sandstone; *d*, diabase-tuff; *e*, hornblende-porphyrite; *f*, augite-porphyrite, somewhat schistose.

The black Mariposa clay-slates begin at the tunnel and adjoin the serpentine on the west; they contain layers of tuffaceous sandstone and are again adjoined on the east by a dark-brown, fine-grained tuff. This tuff shows under the microscope colorless fresh augite fragments, in part altering to greenish uralite; between the augites lie fragments and aggregates of feldspar. The rock is greatly altered by development of secondary amphibole, biotite, etc.

Adjoining this tuff is a dike of normal greenish-gray hornblende-porphyrite with black hornblende phenocrysts and smaller white feldspars. East of this again is a greenish-brown, distinctly schistose augite-porphyrite greatly altered by secondary mineral growth.

On the whole, it appears probable that the hornblende-porphyrites are in part later dikes in the tuffs and diabases, though they undoubtedly in general belong to the same period of eruption.

Pyrite and pyrrhotite do not appear extensively in these rocks in the Nevada City tract.

THE PLEASANT FLAT URALITE-DIABASE DIKES.

Occurrence.—Across the diorite mass of Pleasant Flat extends a narrow area of fine-grained, dark-green rock, very evidently the continuation of the porphyrite area north of the Fair-ground, and similar rocks are found at many other places in the diorite area.

According to the evidence obtained at the narrow promontory separating Pleasant Flat from Stocking Flat, as well as at several other localities in the vicinity, this rock occurs as dikes in the diorite. On the hillsides the deep weathering makes the contacts uncertain. Very fine dikes, from 4 to 6 feet wide, of the same rock are exposed at the contact of diorite and serpentine at the head of Stocking Flat; they also occur in the serpentine.

Description of rocks.—All these rocks are chiefly fine-grained diabases, greatly altered by uralitization, which as a rule has left no augite, and by a more or less extensive recrystallization of the whole mass. A specimen from the contact dike, head of Stocking Flat (168 N. C.), consists of small grains and imperfect crystals of uralite in a feldspar mass which on the whole has a diabasic structure, although many of the feldspar laths are imperfect and transitions to dioritic structure appear. The character of the feldspars can not be well determined under the microscope, as very much secondary biotite and hornblende has developed in them. Ilmenite or titaniferous iron ore is present, but not any pyrite.

A partial analysis of this rock by Dr. Peter Fireman gave:

	Per cent.
SiO_2	51.29
CaO	6.57
K_2O	.34
Na_2O	4.39

Taking into consideration the fact that several per cent of the lime must belong to the uralite, it is apparent that the feldspar approaches an andesine.

One of these uralite-diabases contains a few small prisms of brownish, probably primary, hornblende, and in the same area are many smaller dikes of hornblende-porphyrite.

Weathering.—Like the Banner Hill diabase and porphyrite, the rocks in this area are deeply decomposed, and weather on the surface to the same dark-red clayey soil, from which occasional outcrops of more resistant rocks protrude. This fact makes it extremely difficult, except along the more deeply trenched creeks, to clear up the genetic relations of the different varieties and their relation to other formations. On the Red Hill, and especially on the slope of Deer Creek facing north, the surface decomposition and oxidation reaches a depth of 20 feet or more.

Relation to other rocks.—Toward the argillites and schists of the Calaveras formation the diabase and porphyrite border with intrusive contact. In the southwestern part of the Banner Hill tract there are abundant contact breccias and dikes in the argillites. At the bluff just east of the Home mine (Deer Creek) the nearly massive uralite-diabase cuts across the Calaveras contact-metamorphosed quartzitic schists, showing the later and intrusive character of the former.

From the Home mine northward there are many dikes of diabase in the sedimentary schists. To some extent they are pressed and converted into secondary aggregates, but at many places, such as below the Wyoming mill and in Woods Ravine below the Nevada City mill, the relation of the two rocks is unmistakable.

The Mariposa clay-slates appear, as indicated by the relations stated above, to have been laid down practically contemporaneously with the eruption of the diabases and porphyrites; this is further confirmed by the tuffaceous exposures in the Merrimac mine and a short distance above the Washington mine, where the tuffs gradually change into clay-slates, a relation expressed on the map by the interlocking character of the contacts.

The relation of the series to the diorites and serpentines has already been referred to.

THE DIABASE DIKES IN THE MARYLAND SERPENTINE.

To the north of the railroad in the vicinity of the Maryland mine the serpentine contains a number of diabase dikes, usually following the same direction as the veins of the Idaho system, that is, west-northwest. The width of these dikes ranges up to 50 or 100 feet. The best preserved rock is found in the hanging wall of the Kentucky mine; it is hard, greenish-gray, medium-grained, and contains small grains of pyrite. Under the microscope the more or less regular lath-shaped feldspars with narrow striation and extinctions suggesting andesine are prominent, and their arrangement is that of the normal diabase structure; they contain abundant chlorite and white mica. There are remains of colorless augite, but the mineral is mostly converted into uralite, epidote, and chlorite, the latter filling the triangular interstices between the feldspars. The titaniferous iron ore is converted into milky titanite.

Other dikes on the Nevada City road opposite the Coe shaft and 500 feet northeast of it are similar, the latter containing remains of brown hornblende. The dike-like mass beginning north of the Maryland mine and extending up toward the Spring Hill is extremely affected by chloritic decomposition, but was once probably a diabase.

THE MARYLAND DIABASE AREA.

Extent.—Beginning on South Wolf Creek, this area extends up to the reservoir southeast of the Maryland mine in a rough crescent form.

Description of rocks.—The rocks are dark-green, medium- to fine-grained, normal diabases, characterized by the presence of dark-brown hornblende besides the augite.

A typical rock, unusually fresh, occurs on this road 425 feet west of the reservoir above the Maryland mine (121 G. V.). It is medium-grained and carries much pyrrhotite in small grains.

Under the microscope the feldspars appear in long lath-like form, in part also as irregular grains. The twin lamellæ are rather broad, but the symmetrical extinctions indicate that the prevailing feldspar is less basic than the labradorite. Between the laths lies, in places, a little of a fine-grained, interwoven aggregate of feldspar, sometimes showing an approximation to spherulitic structure. The augite is colorless and shows imperfect outlines, indicating that its recrystallization in part preceded that of the feldspar. Most of the augites are surrounded by a fringe of evidently primary brown hornblende. There is very little ilmenite or titanic iron ore, but a large amount of pyrrhotite and pyrite, the occurrence of which in the fresh augite and feldspar renders its primary character evident (fig. 2). Some of the interstices between the feldspars are filled by chlorite.

An analysis of this rock by Dr. H. N. Stokes gave:

	Per cent.
SiO_2	51.01
TiO_2	.98
P_2O_5	.17
CuS	Trace.
Al_2O_3	11.89
Cr_2O_3	.04
Fe_2O_3(*a*)	1.57
FeO(*a*)	6.08
FeS_2	1.73
MnO	Trace.
CaO	10.36
MgO	8.87
K_2O	.15
Na_2O	4.17
H_2O below 110° C	.24
H_2O above 110° C	2.09
	99.35

a Approximate only, because of presence of sulphides.

The rock appears to be a very typical diabase. Considering that several per cent of the CaO must belong to the augite, it is at once apparent that the average composition of the feldspars does not reach (Ab_1An_1), but is rather that of an andesine. Sulphide has in the analysis been calculated as FeS_2, only that compound being present in the sample; in the specimen from the same outcrop from which the thin sections were taken a large quantity of pyrrhotite was identified by Dr. Stokes.

FIG. 2.—Primary pyrrhotite in augite; in diabase, 121 G. V. Magnified 60 diameters. Black=pyrrhotite; *a*, augite; *b*, uralite; *c*, chlorite.

Other rocks in the vicinity are similar, but usually contain more chlorite; in some the pyrrhotite is more or less completely replaced by black iron ores.

The diabasic rocks from the hanging wall of the Idaho-Maryland vein are grayish-green, extremely chloritic rocks, often containing much carbonates and sericite. In thin section the all-pervading chlorite generally veils the original character, but it is suspected that several varieties of rocks are present. The rock from the hanging wall, fifteenth level (145 G. V.), shows chiefly a mass of feldspars of imperfect lath-like form, between which lies much chlorite. The extinctions indicate a rather acid plagioclase. Other slides, from the sixteenth level near the incline, show a chloritic mass in which lie very long and narrow lath-like feldspars, the structure in fact approaching the pilotaxitic groundmass of some of the porphyrites. Still another specimen, from the mine dump, shows a distinct tuffaceous character. This is not so surprising, for the workings of the mine now extend under the area indicated on the surface as schistose porphyrite, which area in fact is largely composed of pressed porphyrite-tuff.

A partial analysis of No. 145 G. V., by Dr. H. N. Stokes, gave·

	Per cent.
SiO_2	57.94
CaO	1.85
K_2O	.21
Na_2O	8.95

The large percentage of Na_2O and the small amount of CaO are very unexpected, but the rock is much altered and it is not safe to draw any conclusion as to its original composition.

The principal rock exposed in the shaft of the South Idaho is a very typical uralite-diabase. Between large, long, and slender laths of feldspar, well filled with secondary epidote, lies fibrous, pale-green, uralitic hornblende. Narrow veins of a white mineral cross the specimen, evidently related to epidote, but showing exceptionally low colors of interference; the extinction is oblique to the well-developed cleavage. A partial analysis by Mr. George Steiger showed the mineral to contain:

	Per cent.
SiO_2	42.30
Al_2O_3 (with some Fe_2O_3)	30.10
CaO	17.30
MgO	Very little.
Ignition	4.70

The mineral must thus be regarded as an epidote exceptionally poor in iron.

The rock in the sharp railroad curve 2,100 feet south of the Maryland mine is very fine grained uralitic diabase, in which, however, the typical structure is less well developed. Remains of augite and brown hornblende were noted. The slide contains veins filled with white epidote and chlorite, together with a secondary mineral with strong double refraction, probably scapolite.

Relation to other rocks.—The irregular contact toward the gabbro on the west has already been noted, the diabase intruding as dikes in the former rock. On the northeast the contact toward the serpentine is distinct. On the east the diabase borders, with extremely indistinct contact, more in the nature of a transition, toward the schistose porphyrite-breccia.

THE AUGITE-SYENITE OF SOUTH WOLF CREEK.

Half a mile east of the Grass Valley railroad station is a small area of a grayish-green, medium-grained rock of diabasic appearance, usually containing scattered grains of pyrrhotite. The rock occurring 1,200 feet west of the lower sulphuret works (64 G. V.) consists, as seen in thin section, of lath-shaped plagioclase crystals much clouded and filled with micaceous products, and augite as short stout crystals or filling triangular interstices between the feldspar laths. Cementing all these constituents is a fresher and clearer feldspar without twin lamellæ, which evidently is orthoclase. Small amounts of uralite and chlorite are present, while most of the titanic iron ores are converted to leucoxene. A partial analysis of this rock by Dr. H. N. Stokes gave:

	Per cent.
SiO_2	51.47
CaO	7.72
K_2O	3.76
Na_2O	2.92

The presence of such a large quantity of K_2O in this rock is remarkable and allies it to the augite-syenites, or more correctly to the monzonites of Brögger. It is not, however, probable that it is a geologically independent body, for its affiliations are clearly with the Maryland diabase area, and it is probably only a facies of that rock. The relations of this area to the surrounding serpentine and Calaveras formation are obscured by the extensive weathering.

THE DIABASE AND PORPHYRITE DIKES IN THE CALAVERAS FORMATION OF GRASS VALLEY.

The medium-grained to aphanitic, dark-green dikes in the Calaveras formation nearest to the granodiorite are, as a rule, fine-grained diabases and diabase-porphyrites, uralitized in part. They frequently contain pyrrhotite intergrown with black iron ores; at least a part of this pyrrhotite is probably primary. The exposures are not satisfactory, the dikes occurring in the central part of the city.

From the Crown Point to north of the New Eureka there extends, in closest connection with the serpentine, a series of dike-like masses of varying structure. They are chiefly diabasic rocks consisting of augite surrounded by brown hornblende, feldspars without pronounced lath shape and often not striated, pyrrhotite, and black iron ores. But hornblende-augite-porphyrites with fine-grained, holocrystalline groundmass also occur. All of these rocks are intensely altered; the augite and hornblende is changed to uralite, bastite, serpentine, and chlorite; the serpentinization is sometimes very pronounced; the feldspars are altered to strongly bi-refracting aggregates, which in part are muscovite, in part probably a scapolite. The black iron ores are converted into leucoxene and chlorite, while sometimes secondary pyrrhotite is also found.

In the New Eureka shaft a series of very peculiar altered serpentinoid rocks were found, consisting of a fine felted mass of chlorite and serpentine containing large distinct foils of white and reddish-brown mica. It seems evident that the diabase and porphyrite are here undergoing a process of serpentinization, but in what degree the serpentine to the northwest has resulted from these rocks is not clear.

In the St. John shaft a very varied and interesting series of rocks have been exposed. The relations of the serpentine to this are indicated in fig. 21, p. 220. The rocks comprise hornblende-diabases, sometimes also with primary brown mica; granular rocks consisting of reddish-brown mica, feldspar, and abundant quartz; and, finally, grayish-green quartz-hornblende-porphyrites. The latter carry idiomorphic hornblende and feldspar in a holocrystalline groundmass made up of imperfectly lath-like plagioclase, between which lies unstriated feldspar and quartz. Nearly all of the rocks carry pyrrhotite in intergrowth with magnetite, and the former is in part quite surely primary. The minerals in the rocks are extremely altered to bastite, chlorite, micaceous products, and probably also to scapolite, by the ordinary metamorphic processes. Thermal waters have in addition produced abundant calcite and pyrite.

It appears as if the final result of the metamorphic processes would have been a serpentinoid rock consisting of serpentine, chlorite, and actinolite, in which lie larger bastite crystals.

THE NORTH STAR DIABASE AND PORPHYRITE AREA.

Extent.—This area extends in roughly rectangular form from near the North Star up toward the northwestern andesite area. It is bounded

FIG. 3.—Intergrowth of primary pyrite and pyrrhotite with titanic iron ore; in diabase (34 G. V.). Magnified 112 diameters. *a*, augite; *b*, hornblende; *c*, plagioclase; *d*, titanic iron ore; *e*, pyrite; *f*, pyrrhotite.

by the Calaveras formation on the west and by the granodiorite on the east, north, and south.

Description of rocks.—In the southeastern portion of the area medium-grained diabases prevail, in part very fresh and unaltered rocks. Typical specimens were obtained 1,600 feet southeast of the North Star mine (32 G. V.), 3,000 feet north of the Omaha mine (34 G. V.), and 1,300 feet north of the same mine (108 G. V.).

The second of these (34 G. V.) is a medium-grained, dark-green, fresh rock in which the black pyroxene and light-green feldspars are plainly visible. Grains of pyrite and pyrrhotite are scattered through the mass. Under the microscope the rock is shown to be very fresh, almost the only secondary mineral being a little chlorite associated with the hornblende.

The plagioclase occurs partly as long, lath-like crystals with narrow striation, the extinction indicating an oligoclase or andesine, partly also as irregular grains indenting the laths, the effect being often a ragged or patched appearance. Many of the irregular feldspar grains do not show twin lamellæ. The augite forms colorless grains, rarely idiomorphic, but often notching the feldspar laths, the whole indicating a more or less simultaneous crystallization. The augite is surrounded by sharply defined, brownish-green hornblende, not always of the same orientation. This hornblende is evidently a later magmatic growth, and not a secondary mineral. There is probably also a little quartz between the feldspar grains. The black titanic iron ore, pyrite, and pyrrhotite are clearly of primary origin, and the earliest products of consolidation, being included in all of the other minerals (fig. 3). The three minerals occur in very intimate intergrowth as irregular grains, the sulphides being included in the oxide, and vice versa. The titanic iron ore is most abundant. The structure, while in general diabasic, is not very typically so, on account of the less perfect lath-like development of the feldspar.

This rock was analyzed by Dr. H. N. Stokes, with the following result:

	Per cent.
SiO_2	53.19
TiO_2	1.34
P_2O_5	.13
CuS?	....
Al_2O_3	17.12
Cr_2O_3	None.
Fe_2O_3 (a)	4.35
FeO (a)	5.16
FeS_2 (b)	.94
MnO	Trace.
BaO	Trace.
CaO	9.39
MgO	3.98
K_2O	.28
Na_2O	2.79
H_2O below 110° C	.17
H_2O above 110° C	1.21
	100.05

[a] FeO and Fe_2O_3 only approximate, on account of presence of sulphides.

[b] Calculated as FeS_2, but much Fe_7O_8 also present.

The rock is a typical diabase in composition and very similar to the Maryland diabase. In all respects similar to this rock is the specimen 32 G. V., referred to above.

Other specimens, such as 108 G. V. and 114 G. V., at Central North Star, show a much more typical diabase structure. They are uralite-diabases, with a large amount of black iron ore.

The rocks in the vicinity of the North Star mine are in general finer-grained, dark-green, and frequently porphyritic by small feldspar and more rarely augite crystals. They may in general be characterized as uralitic diabase-porphyrites ranging down into uralite-porphyrite with pilotaxitic groundmass. These rocks are greatly decomposed, abundant chlorite, epidote, and micaceous product being formed, as well as leucoxene from the titanic iron ore. The feldspars are not recrystallized as in the typical dynamo-metamorphic areas, but alter into epidote, micaceous products, and perhaps also scapolite. Segregations of secondary products occur, chiefly characterized by abundant epidote. Such a segregation was found on the dump of the tunnel of the Star placer mine in Wolf Creek, a short distance above the Omaha mine, and consisted of a coarse mass of epidote, magnetite, and pyrite, with crusts of chabazite; it was assayed and found to contain 1 ounce of silver per ton, but no gold.

A hornblende-porphyrite of fresh appearance was noted on a dump 300 feet east of the Rocky Bar deep shaft. It probably occurs as a dike in the prevailing denser diabase-porphyrite, which is filled with epidote and pyrite.

The prevailing rock at the Peabody mine is a fine-grained diabase. In the northwestern part of the area dark-green porphyrites, with unusually large white feldspar crystals, appear.

On the whole, there is in this area no marked dynamo-metamorphism, but an extensive alteration, resulting chiefly in epidote, chlorite, and pyrite, and there is evidently no new feldspar formed. This alteration is distinct from the dynamo-metamorphism, but, on the other hand, it is also distinct from and surely not caused by the thermal waters forming the quartz veins. Epidote can evidently not be formed by this thermal process, and the alteration shows besides no dependence on the quartz veins, not growing more intense as these are approached.

Weathering.—The rock in this area is deeply decomposed and covered by a clayey, red residual soil. The only good exposures are afforded by the mining operations. This zone of extreme disintegration and decomposition is sometimes 30 to 40 feet deep.

Relation to other rocks.—The contact on the west with the Calaveras formation is not well exposed. Near the North Star mill a 12-foot-wide mass of siliceous and jaspery rock, reddish or yellow, and containing nests and cavities with chalcedonite, lies on or near the contact, but of normal contact metamorphism there is no clear indication.

THE OSBORNE HILL DIABASE, PORPHYRITE, AND BRECCIA AREA.

Extent.—This large area occupies a considerable portion of the southeastern part of the Grass Valley tract. Beginning on South Wolf Creek, southeast of the railroad station, it extends by the Empire and W. Y. O. D. mines and finally forms the great prominent ridge of Osborne Hill.

Description of rocks.—The rocks are in general fine-grained to aphanitic, dark-green, and the constituents can rarely be made out with the naked eye. While not generally affected by dynamo-metamorphism, the rocks are often deeply changed by chloritic and epidotic alteration. Both massive rocks and breccias occur.

At the northern end of the area, between the granodiorite and the Calaveras formation, the rock is a dark-green porphyrite-breccia with fragments of siliceous argillite; it is highly altered and has evidently also been subjected to pressure. Films of chlorite and secondary hornblende obscure the relations of the minerals. Scattered grains of magnetite and pyrite occur in intimate intergrowth.

Near the Empire and W. Y. O. D. the rock is very fine grained uralite-diabase, at the latter place very rich in pyrite. The dark-green, fine-grained rock from the dump of the Golden Treasure shaft consists, in thin section, of abundant pale-green uralite in grains or roughly outlined crystals, containing magnetite and pyrite intergrown. The feldspars constitute an entirely clouded mass, once evidently forming lath-like crystals.

Very fine grained diabases occur in the vicinity of Houston Hill. The structure in thin section, which with low magnifying power appears almost pilotaxitic, becomes with higher power very typical diabasic granular by long triclinic feldspar laths, between which lie triangular masses, also anhedral or roughly idiomorphic crystals of colorless augite, undergoing a direct transformation into chlorite. The titanic iron ores are transformed into leucoxene and pyrite, and pyrrhotite appears in connection with chlorite. Often there are large quantities of uralite and epidote and new-formed aggregates of quartz (and feldspar?) containing amphibole needles.

A rock from near the granodiorite contact at Leeman's ranch, 4,000 feet east of the Omaha mine, is a dark-green, medium-grained rock of diabasic appearance and containing a large amount of grains of pyrite. Under the microscope its greatly altered character is evident. There is no augite, but much brownish-green hornblende in irregular grains and shreds. An original mass of lath-like feldspars is entirely obscured by opaque aggregates of doubtful character, probably in part kaolin. Allotriomorphic aggregates of secondary quartz, possibly also some new-formed feldspar, lie between the altered feldspars. Magnetite and pyrite, in part intimately intergrown, are scattered through the mass, in the feldspar, the hornblende, and the secondary quartz aggregates; there is no calcite. The rock contains a trace of copper.

Porphyrites also occur abundantly in this area. Northeast of the Empire hoisting works, and 1,200 feet distant, a greenish-gray rock with small white feldspar crystals was noted. It contains scattered grains of pyrite; one grain of chalcopyrite was also determined. Under the microscope the structure appears brecciated; the fragments are of a porphyrite, the augite or hornblende being converted into chlorite. The groundmass is very unusually fine grained, and has a probably hypocrystalline, hyalopilitic structure, though the glass was not identified beyond doubt; it may, however, have become devitrified. In places the rock is amygdaloid, the cavities being filled with chlorite.

Specimens from a shaft on the Lincoln vein, due east of the Golden Treasure shaft, show a typical augite-porphyrite; the idiomorphic feldspars are clouded by kaolin and strongly double-refracting aggregates, possibly of scapolite; the idiomorphic augite is usually characterized by porphyritic twin lamellæ. The groundmass is holocrystalline and composed of small uralite and clouded feldspar grains. Much pyrrhotite is present, intergrown with magnetite.

The rocks from the southern end of Osborne Hill are generally grayish-green, highly altered porphyrites, with a strong development of epidote.

The summit and larger part of the eastern slope of Osborne Hill is composed of a breccia of differing coarseness, chiefly made up of fragments of porphyrite and diabase-porphyrite, together with less of a gray or brownish, finty, sedimentary rock. The feldspar in the porphyrites is usually altered to epidote and other secondary minerals, while the augite is converted to chlorite.

Weathering.—Over practically the whole area rests residual soil of greater or less depth, red color, and clayey character, and the exposures are only rarely satisfactory.

Relation to other rocks.—The brecciated character of the rock mass near the Calaveras formation has already been mentioned. Along the granodiorite contact the exposures are not satisfactory at any place, but dike-like masses of granodiorite in diabase were noted at many places from Little Wolf Creek southward.

THE ORLEANS QUARTZ-PORPHYRITE DIKES.

Beginning near the Orleans mine and extending at least as far as the Daisy Hill mine are a series of dikes of quartzose porphyrite, occupying a place similar to that of the dikes from the eastern part of the Banner Hill tract or some of the rocks from the St. John mine. This dike system probably extends farther south, as similar rocks are found at the Lafayette tunnel and other places on the western slope of Osborne Hill, but the outcrops are so obscured by heavy soil that it is scarcely possible to trace the dikes farther. Besides, the quartz-porphyrite at the Lafayette tunnel is less quartzose than that farther north, and appears to grade over into normal porphyrite. A typical rock from the New Ophir claim (140 G. V.) is of light grayish-green color and contains some epidote. The grayish phenocrysts of feldspar, as well as augite or hornblende, now converted into chlorite, lie in a dense, almost flinty groundmass.

The plagioclase phenocrysts appear, under the microscope, filled with epidote and micaceous products, while the augite or hornblende is converted into uralite, chlorite, and epidote. The groundmass consists either of short feldspar laths, between which lies a little quartz, as a cement, or of a micropoikilitic intergrowth of feldspar laths and grains with quartz.

The rock was analyzed by Dr. H. N. Stokes, with the following result:

	Per cent.
SiO_2	63.39
TiO_2	.44
P_2O_5	.14
Al_2O_3	16.58
Fe_2O_3	1 41
FeO	3.08
MnO	Trace.
BaO	.11
CaO	4.76
MgO	2.15
K_2O	2.79
Na_2O	3.47
H_2O below 110° C	.22
H_2O above 110° C	1.87
	100.41

The composition is almost identical with the quartz-porphyrite from the Banner Hill area, the analysis of which is given elsewhere.

The relation of the quartz-porphyrite to the surrounding diabase is not clear at the main dike, but the intrusive character is apparent in the case of a small dike of the same material outcropping in the bed of the creek a few hundred feet farther down.

THE AMPHIBOLITE GROUP.

DEFINITION.

Under the name "amphibolite" are here included massive or schistose rocks composed chiefly of hornblende, usually with smaller quantities of quartz, feldspar, epidote, and chlorite. These rocks are here in most cases products of dynamo-metamorphic action upon primary igneous rocks of the composition of diabases or porphyrites.

THE INDIAN FLAT AMPHIBOLITE AREA.

Extent.—This amphibolite area really forms the northern end of the Pittsburg diabase and porphyrite belt. As the process by which the amphibolites have been produced has in fact affected all of the rocks in the belt mentioned, it is necessary to discuss to some extent the alteration over the entire area. It is very evident that the extreme mechanical deformation causing schistosity is not necessary for the production of thoroughly metamorphic amphibolitic rocks. The rocks designated "amphibolites" are in general schistose, though rarely very prominently so, and are not separated by a sharp line from the less altered diabasic or porphyritic rocks.

Description of rocks.—The less schistose amphibolites and the uralitized diabases are not readily distinguished by the naked eye, the fine-grained structure and dark-green color being common to both.

The first stage in the metamorphism consists in the uralitization of the abundant augite (and rarer hornblende) in the primary rocks; at the same time the ends of the crystals feather out in ragged and divergent aggregates of light-green hornblende, and needles of the latter scatter through the feldspars. It is not necessary, however, that this process should be completed before the alteration proper begins. The latter consists in the forming of clear, allotriomorphic granular aggregates of generally unstriated feldspars, quartz, epidote, with abundant newly formed green, frequently idiomorphic, hornblende and dark brown biotite; this hornblende should not be designated "uralite;" the forms assumed are well indicated in a figure of the Conrad tunnel amphibolite in a paper on the Ophir mines.[1] Besides these minerals, magnetite, pyrite, and pyrrhotite are formed and contained, equivalent to the other components, in the secondary allotriomorphic mass. This new-formed mosaic encroaches gradually on the original minerals; the remaining feldspars appear as remnants clouded by muscovitic minerals and epidote. The eventual result is the conversion of the rock into an even-grained, clear, and fresh mosaic, an aggregate of the secondary minerals.

Muscovitic minerals are not, as a rule, formed in this process, nor is chlorite, though subsequent alteration may produce them in the amphibolites. Very characteristic for this area is a strong development of secondary biotite. That contact metamorphism has not caused this alteration is indicated by the fact that the black Mariposa clay-slates, easily susceptible to the influences of that process, are not notably altered, while the surrounding diabasic rocks have been considerably changed. Toward the end of the area northwest of Indian Flat, however, it is possible that contact metamorphism is in part responsible for the alteration.

In the tuffaceous rocks from near the Herring reservoir the metamorphic processes are already noticeable. Uralite largely replaces

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[1] Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1894, p. 258.

augite, and a reddish-brown mica develops abundantly in the uralite; in some crystals the tendency appears to be to convert the whole mass into biotite of similar orientation. Between the original feldspars, and also to some extent in them, the biotite is also developing, as well as abundant needles of new amphibole (104 N. C.). In other specimens (105 N. C.) from the same place new allotriomorphic feldspar aggregates appear, forming with biotite and hornblende a clear mosaic. Pyrite and pyrrhotite, as well as some black iron ores, are also among the new-formed minerals making up the mosaic, the sulphides being formed contemporaneously with the biotite.

From the Pittsburg mine down to Deer Creek the prevailing rocks are dark-green uralite-diabases; remaining kernels of augite often indicate the derivation of the light, bluish-green uralite; the edges of the uralite are extremely frayed and ragged, and needles of new-formed hornblende penetrate the feldspar. The original feldspars are clouded and filled with micaceous aggregates and epidote; between them and in them new, clear mosaic aggregates are forming of feldspar, hornblende, quartz, etc.

North of Deer Creek the alteration increases; the rock 1,100 feet northwest of the Indian Flat schoolhouse is typical (161 N. C.). It is a fine-grained, very slightly schistose amphibolite of dark-green color. In thin section the rock presents a blotched appearance, from the occurrence of larger white spots in the more even-grained prevailing mass. The latter is a clear allotriomorphic mass of biotite and green hornblende in irregular but sharply defined grains and foils, with grains of new-formed feldspar. The white spots are the remains of larger plagioclase crystals, now clouded and filled with minute hornblende needles. The process by which this mass is converted into the clear mosaic aggregate is very well shown, the latter corroding the older feldspars in all directions; sometimes the feldspar is cut by veins of the mosaic. In other rocks from this vicinity remains of augite are seen.

Toward the Oro Fino mine, beyond the area of the special sheet, the amphibolite becomes more schistose and more completely recrystallized.

From the clear, fresh character of the new mosaic and the clouded and altered remains of older feldspar the conclusion might be drawn that this alteration precedes the formation of the new mosaic, or, in other words, that the rock was already considerably altered before the dynamo-metamorphism took place. This conclusion is, however, of doubtful value, for the new-formed feldspar is probably albite and much more resistant to alteration than the old soda-lime feldspar. While deformations of minerals by pressure are met with in these rocks, they are not nearly so prominent as, for instance, in the adjoining aplite dike or in the Calaveras sandstones of Grass Valley. Quartz being most susceptible to crushing, rocks containing it show most plainly the purely mechanical effects of dynamo-metamorphism.

THE BRUNSWICK AREA OF SCHISTOSE PORPHYRITE-BRECCIA.

Extent.—Beginning southeast of the Maryland mine, bordering against diabase, this area extends southeasterly by the Gold Point and Brunswick mines, adjoined on the northeast by serpentine and on the southwest by the andesitic tuff, to beyond the limits of the special maps.

Description of rock.—The rock over the whole area is more or less intensely affected by dynamo-metamorphism and has become schistose. At the Lucky mine and at the Brunswick the schistosity is more strongly developed, producing amphibolitic and chloritic fissile rocks. Less altered rocks (97 G. V.) occur on the road along the Gold Point ridge, at an elevation of 2,700 feet. The rock is a greenish-gray, fine-grained breccia, very hard and compact and roughly schistose. Lighter grayish or brownish fragments of siliceous argillite appear to shade over into the darker green fragments of porphyrite. Under the microscope the porphyrites are shown to be chiefly augitic, with very fine grained, partly pilotaxitic groundmass. A large part of the augite has been converted into uralite. The cement of the breccia is a very confused mass of chlorite, epidote, white mica, and needles of hornblende. Grains of pyrrhotite also occur, mostly connected with chlorite.

Least altered is the augite-porphyrite-breccia from near the edge of the Grass Valley tract, 500 feet east-southeast of the small Maryland shaft on the ridge (120 G. V.). It is a dark-green, very hard, fine-grained rock of slightly fragmental aspect. A partial analysis of this pure breccia, by Dr. H. N. Stokes, gave:

	Per cent.
SiO_2	47.03
CaO	13.20
K_2O	1.90
Na_2O	2.84

The low percentage of silica and large amount of calcium in this rock are somewhat exceptional; the prevailing feldspar must be of quite basic character.

Weathering.—The surface of this area is deeply decomposed, the dark-red, clayey soil making the exposures, as a rule, very unsatisfactory. At the Gold Point mine, 136 feet from the surface, the porphyrite-schist is entirely disintegrated to a crumbling yellowish rock.

CHAPTER V.

THE SEDIMENTARY ROCKS OF THE BED-ROCK SERIES.

GENERAL FEATURES.

The sedimentary rocks, consisting of clay-slate (argillite), siliceous argillite, quartzitic sandstone, and chert, occupy relatively small areas in the tracts described. Only rarely can the stratification be recognized, and it is then about vertical, and approximately coincides with the schistosity. The latter is always nearly perpendicular, though a slight dip to the east may sometimes be recognized.

CALAVERAS FORMATION.

DEFINITION.

The Calaveras formation includes the sedimentary rocks of Paleozoic age occurring in the Gold Belt. It is believed on good grounds that most of this formation belongs to the Carboniferous, but it is possible that older rocks may also be present, the scarcity of fossils making identification difficult.

In the areas referred to this formation no fossils have been found, and the evidence of age is only circumstantial. The beds are altered, but not in general completely recrystallized, though, under the influence of dynamic and contact metamorphism, they grade into normal crystalline schists.

The areas in the Grass Valley tract are the continuation of the sedimentary formations about Auburn and Colfax, in which a few fossils distinctly indicating Lower Carboniferous age have been found. The best locality is at the old limestone quarry 2 miles west of Colfax, from which Mr. C. D. Walcott has identified the characteristic corals *Clisiophyllum gabbi* Meek and *Lithostrotion whitneyi* var. *sublævis* Meek. The areas in the Banner Hill tract are the continuation of the series extending up by North Bloomfield and the Delhi mine, in which masses of limestone with crinoid stems have been found along the South Yuba River, indicating at least a Paleozoic age.

These sedimentary rocks are more resistant to weathering than the granodiorite, and in the Banner Hill and Nevada City tracts form a ring of hills rising like an amphitheater around the broad depression occupied by the granodiorite.

THE FEDERAL LOAN AREA.

Rock description.—The Federal Loan area contains, well exposed in the deep canyon of Deer Creek, a very peculiar sedimentary rock, black to dark-brown in color, very hard and dense, with a fracture ranging from imperfectly conchoidal to splintery. Minute grains of sulphides are abundantly scattered through it. It only rarely, and then in decomposed outcrops, shows a trace of schistosity, but is in general entirely massive. It looks much like certain very dense products of contact metamorphism, usually called hornfels, but the extent of the area outside of the special map shows that its occurrence is not dependent on the proximity of the granitic rocks. On the contrary, it forms an important part of the Calaveras formation in the area of the Colfax sheet, beginning north of Colfax and extending, several miles wide and magnificently exposed in the canyons of the South and Middle Yuba, up to the northern limit of that sheet, where it is cut off by igneous rocks. Within this area it becomes schistose in streaks, and then appears as siliceous clay-slate; it also contains some smaller lenses of limestone with crinoid stems (South Yuba Canyon). This rock may for the present purpose be called *siliceous argillite*, the word argillite being used to designate a fine-grained, clayey, sedimentary rock, whether schistose or not, which has undergone some alteration. It presents some similarity to the cherts of certain sedimentary series, but it does not occur in distinct layers as the radiolarian chert (phthanite) of the Coast Ranges, nor is it, like certain other cherts, derived from limestone. A certain similarity to lydite (Kieselschiefer) is also noted, but it contains much less silica than either chert or lydite. It is probably to be regarded as having been originally deposited as a siliceous clay, partly by the agency of radiolarian organisms, of which there are, indeed, indistinct traces in the rock. The metamorphism which the rock has undergone can not, as stated above, be regarded as contact metamorphism, but is more likely part of the regional and evidently dynamic metamorphism which has affected all of the sedimentary rocks of the Calaveras formation.

In the excellent outcrops along Deer Creek above Federal Loan, the black siliceous rock is seen to contain indefinite streaks of lighter color, which have a general north-south direction; this may be a faint remaining trace of stratification.

A rock from the ditch opposite Federal Loan, and 1,300 feet from the contact (23 N. C.), corresponds well to the above description; pyrrhotite is contained in minute grains and veinlets.

Under the microscope it resolves into an extremely fine grained, allotriomorphic, holocrystalline aggregate of quartz and probably feldspar. Very intimately intermingled with this mosaic are small flakes of reddish-brown biotite, and there are abundant larger and smaller grains of pyrrhotite, in all probability of contemporaneous formation with the biotite. A little carbonaceous organic matter is also present. The slide is dotted by a few small round and clear spots of a coarser quartz aggregate. It is not impossible that these may be radiolarian remains.

The unaltered wall-rock from the Federal Loan mine (35 N. C.) is of similar appearance, but contains a few grains of pyrite, besides pyrrhotite and minute seams of calcite, noticeable only upon treatment with hydrochloric acid.

Under the microscope it appears a little coarser than the rock just described, and presents remains of a clastic structure by larger rounded grains of quartz or feldspar. The main mass is the same intimate mixture of brown, in part idiomorphic biotite foils and allotriomorphic quartz-feldspar mass. The feldspar is not quite fresh, being in part filled with micaceous minerals. Most of the sulphides are undoubtedly contemporaneous with the formation of the mosaic.

This rock was analyzed by Dr. W. F. Hillebrand, with the following result:

Analysis of wall rock from Federal Loan mine.

	Per cent.
SiO_2	73.63
TiO_2	.52
Al_2O_3	10.54
Fe_2O_3 *a*	1.87
FeO *a*	
CaO	2.47
SrO	Trace.
BaO	.12
MgO	1.84
K_2O	1.89
Na_2O	1.81
Li_2O	Trace.
P_2O_5	.13
CO_2	.62
Fe_7O_8	3.16
Carbon of organic matter	.59
H_2O below 110° C.	.11
H_2O above 110° C.	1.07
	100.37

a Because of organic matter and soluble sulphide, the FeO could not be estimated; therefore all iron after deduction of that needed for Fe_2O_3 is counted as FeO.

The analysis shows that the rock is not a lydite or "Kieselschiefer," as it contains too little silica. On the whole, the composition is similar to that of many so-called "Hälleflinta," although in the latter rock the original clastic structure is wholly lost. It is too acid, on the other hand, for an ordinary argillite.

Weathering.—On the summits of the ridges this rock weathers to a white, soft, clayey mass, such as is exposed along the road to Scotts Flat, a little east of the eastern boundary of the sheet. The weathering is not, however, deep, and the rock on the whole shows comparatively great resistance to this process. Red soil, washed down from the adjacent masses of andesite and porphyrite, usually covers the surface.

Contact metamorphism.—For a few hundred feet from the contact the siliceous argillites are altered to more crystalline rocks; the best exposures are found in Deer Creek below the Federal Loan. The contact is extremely sharp, and near it, as mentioned, a dike of fresh granodiorite occurs in the altered rock. For the first few feet from the contact the sedimentary rocks are converted into medium-grained, grayish, slightly schistose, gneissoid rocks; the grain is of varying coarseness, and the rock presents a spotted appearance from the irregular distribution of the biotite, occurring abundantly as small black foils. A thin section 2 feet from the contact shows a coarse mosaic structure of quartz and feldspar without twin striation, with a few roughly lath-like plagioclase crystals and much reddish-brown biotite in straight foils, in part altered to chlorite. Five feet from the contact the grain of the rock is already finer, and in thin section the mosaic structure of quartz and some not twinned feldspars becomes more pronounced. Abundant small biotite foils and a few cubes of pyrite are inclosed in the fresh quartz grains.

For a few hundred feet back from the contact the rocks show a gradually diminishing grain until the normal structure, previously described, is attained. The typical contact rocks of this type are of brownish or brownish-violet color, fine-grained, but not flinty or splintery, and the biotite foils in them may be observed with the magnifying glass.

In thin section these rocks consist of a fine-grained mosaic of quartz and unstriated feldspar, easily resolved by a No. 4 Hartnack objective. Larger foils of reddish-brown mica with irregularly rounded outlines lie between the grains. The biotite is partly converted into chlorite. In the clear mosaic grains are embedded a great number of small biotite foils, the larger hexagonal, the smaller with rounded outlines; magnetite, pyrite, and probably also pyrrhotite, are embedded mostly as small crystals in the fresh quartz and feldspar mass. The sulphides are without doubt formed contemporaneously with the other contact minerals.

THE BANNER HILL AREA.

The sedimentary rocks occupy the northwestern steep slope of Banner Hill. Less altered black argillites of imperfectly schistose character occur at the old Banner mine and in the small area south of the andesite, while along the contact near the North Banner mine and up the creek hornfels or contact-metamorphosed siliceous argillites prevail.

Occupying the broad belt across the summit of Banner Hill is a brecciated zone consisting chiefly of a hard, compact, and well-cemented mass of angular, gray to brown fragments of the same rock that has been described as siliceous argillite from the Federal Loan area.

In thin section the latter rock appears with its characteristic, extremely fine allotriomorphic structure, but with less biotite than near the Federal Loan; other fragments are of igneous rocks, and are identical with the augite and hornblende porphyrites of the adjoining Banner Hill area. The amount of the igneous fragments gradually increases until near that area they prevail and only occasionally gray or brown fragments of the sedimentary rocks appear. The igneous fragments are generally well preserved and show unaltered brown hornblende and greenish augite.

Very characteristic of this breccia is a recrystallization effected between the fragments and also in the sedimentary rock pieces. Allotriomorphic mosaics, sometimes rather coarse, have been formed, and consist of quartz, possibly also some feldspar, with a pale-green, anhedral mineral which from its cleavage and extinctions must be a monoclinic pyroxene, perhaps malacolite, though the small size of the grains did not permit its positive identification; it is certainly not an epidote. More slender greenish needles in the same secondary aggregate are a very light green amphibole. With this mineral combination is associated abundant pyrrhotite, giving evidence of direct connection with it by being surrounded by rims of the same pyroxenic mineral. This pyrrhotite is thus not connected with or formed by the auriferous vein solutions.

A fine-grained quartzitic rock occurring at the head of Little Deer Creek consists of a wholly crystalline allotriomorphic quartz-feldspar mosaic and abundant small grains of monoclinic pyroxene. This peculiar metamorphism of the Banner Hill breccia is interesting, and its cause is not quite clear. It may be the result of contact-metamorphic action of the porphyrite. It can hardly be due to the granodiorite, and of dynamo-metamorphism there is no indication.

THE CANADA HILL AREA.

The ridge to the south of Canada Hill consists largely of argillite, evidently the continuation of the Banner Hill area, covered in part by the andesitic flows. Over the larger part the exposures are very poor, but it is clear that the rock is not much altered. The prevailing rock is a black argillite with much carbonaceous matter, weathering gray and white and breaking in shelly pieces without clear schistosity. It is much softer than the Federal Loan rock, and does not have the splintery fracture of the latter. Where the area narrows, near the edge of the Banner Hill tract, a vertical schistosity about parallel to the granodiorite contact begins to appear. The original bedding of the rock is not clearly indicated.

Along the contact with the granodiorite there is a gradually fading contact zone of hornfels a few hundred feet wide.

THE NEVADA CITY AREA.

Extent and general character.—As a narrow belt, from 400 to 1,500 feet wide, and closely following the granodiorite-contact, the Paleozoic rocks of the Calaveras formation cross the Nevada City tract in a general northwesterly direction.

The rocks are generally very distinctly schistose and consist of black argillites or clay-slates, siliceous argillites, and quartzitic and micaceous schists. In the southeastern part a zone of contact-metamorphic rocks, a few hundred feet wide, lies next to the contact, while from near the Providence mine northward the whole belt is composed of highly altered schists, but whether all of this should be credited to the effects of contact metamorphism is doubtful.

Description of rocks.—Black, more or less fissile argillites occupy the eastern part of the area. The exposures are very poor; diabase-porphyrites, some very rich in pyroxene, occur as detached masses in the slate, and smaller masses of slate are embedded in the igneous rock.

Good exposures are noted where the creek draining Gold Flat crosses the area. Just south of the Orleans vein in this creek is a cropping of hard, brownish, schistose hornfels, with alternating lighter and darker streaks, probably indicating stratification; the schistosity is parallel to these and to the contact; the dip is 85° N. Flat joints dipping east intersect the schist. At Orleans shaft there are some gneissoid contact metamorphics and black clay-slate with knotty surface (Knotenschiefer). The contact metamorphism extends only 500 or 600 feet. Nearer to the diabase, in the same creek, are exposed fissile, dull-black slates containing much carbonaceous matter and finely disseminated pyrite; in these there is no indication of contact metamorphism.

Near the road south of the sulphuret works there are outcrops of fissile, weathered, knotty slates of silvery-gray color.

At the Fortuna mine the contact metamorphism is not strongly indicated. There are black, sooty, slightly knotty clay-slates and harder siliceous slates of a brownish color, indicating a development of biotite.

Farther west the metamorphism becomes more intense, and unaltered slates are no more seen. In the vicinity of the Crosby shaft some highly altered contact schists, streaked brown and green, are exposed, while the dumps indicate that the sedimentary rocks contain many diabasic dikes.

Brownish, highly altered, micaceous schists appear near the contact at the Providence mine. The good outcrops in the bluff near the Home mine show a fine-grained schist streaked brown and green by alternating developments of hornblende and biotite. The bluff is cut by joints dipping east and west at moderate angles, and the dark-green diabasic rocks, not at all or very imperfectly schistose in places, cut squarely across the schistose sedimentary rocks.

On the opposite side of Deer Creek, below the Wyoming mill, occurs a dark-brown, imperfectly fissile argillite with a somewhat knotty surface and showing under the microscope a very fine grained, allotriomorphic mass of quartz, feldspar, and biotite, with much carbonaceous matter. Somewhat schistose, dike-like masses of amphibolitic rock are contained in this argillite.

On the dump of the Wyoming upper shaft were noted dark-brown, fine-grained, crystalline slates with much pyrrhotite in fine dissemination, certain streaks being richer in that mineral than others.

In Wood's Ravine, below the Nevada City mill, good exposures are found of fine grained schists, streaked greenish and brown, cut by diabasic veins and in places containing small, lenticular, and pressed quartz veins, possibly the result of an older period of quartz formation than that to which the productive veins belong.

From here on northward the rocks are principally fine-grained, brownish schists, streaked brown, green, and gray, and often with hornstone-like fracture; there are also some greenish amphibolitic schists, which appear to represent pressed rock of originally diabasic character. In thin section the prevailing rocks consist of fine-grained quartz-feldspar mosaic with sharply outlined grains and flakes of hornblende, epidote, and biotite, and often show a streaky appearance by the arrangement of the latter minerals. This rapid variation and the usually predominant biotite separate them from the slaty amphibolites on the west.

Relation to other rocks.—These sedimentary rocks are distinctly older than the granodiorite on the east and the diabasic rocks on the west, both acting as intrusives toward the Calaveras slates. Some of the diabasic dikes show relatively slight alteration, while others are converted into amphibolitic rocks. Whether this is due to a difference in age of the latter or to differing intensity of the dynamo-metamorphic action is not certain.

The schistosity is in general parallel to the granodiorite contact, but from this the conclusion must not be drawn that the pressure from the intrusive granodiorite has produced the schistosity. In details, such as in the exposures in the crosscut on level 3 in the Nevada City mine, it is shown that the granodiorite cuts across the schistosity, which evidently was as strongly present at the time of the intrusion as it is now. No doubt the granodiorite has exerted a strong pressure on the schist masses, but it has mainly a pushing and bending action on the already formed schists. Toward the Coan mine the schistosity makes a distinct angle with the contact line.

The question of how far the alteration of the slates is due to contact metamorphism is an obscure one. To judge from available evidence from other parts of the special maps, the contact-metamorphosing action has not extended beyond a distance of a few hundred or a thousand feet.

THE GRASS VALLEY AREA.

General description.—This belt of sedimentary rocks, 1,000 to 2,500 feet wide, extends across the northeastern part of Grass Valley. To the northwest it extends under the covering area of andesitic material, as indicated by the dumps at the various shafts along the Alta channel. To the southeast it also probably continues under the andesites, as indicated by the small areas northeast and east of the Electric mine. The outcrops are very unsatisfactory, and consist chiefly of a grayish, medium to coarse grained, quartzitic sandstone and a very carbonaceous clay-slate. The former is characterized by many grains of dark-gray quartz. Near the granodiorite harder, dark-brown, contact-metamorphic rocks appear.

Fresh rocks found in the New Eureka and Crown Point mines look very different. They are hard, black, quartzitic sandstones, composed chiefly of small, clear grains of quartz and similar black argillites with imperfect cleavage, breaking in irregular fragments with smooth, glistening surfaces. The argillites contain many larger clastic fragments, chiefly of quartz, and both rocks contain pyrrhotite in great abundance as grains and seams with quartz. A little crystalline limestone of dark color was found on the New Eureka dump.

Microscopic description.—Under the microscope these rocks present several interesting features. The whole series appears extremely affected by dynamo-metamorphic action, most intensely manifested in crushing and fracturing. The clay-slates are composed of very fine grained aggregates with abundant newly formed muscovite, sometimes biting into the quartz grains, and much carbonaceous substance. A few larger crushed clastic grains were noted. Extreme crushing has practically converted some rocks to a breccia, traversed by small white veins, described below. Others show a pressed structure parallel to the cleavage, and some clastic grains are elongated in the same direction. Grains of pyrrhotite are very abundant throughout.

Still more interesting are the quartzitic sandstones (72, 73 G. V.). The clastic grains are chiefly quartz, while some feldspar, in part with twin lamellæ, is also present. Curved lines of fracture and small veins, chiefly of calcite and quartz, traverse the slides. The cement is recrystallized into an irregularly intergrown aggregate of quartz and feldspar with shreds of biotite, muscovite, and chlorite. Pyrrhotite also enters into the composition of this new-formed mass, and considerable organic matter is present. A few crystals of bluish-gray tourmaline were noted in the cement. The clastic grains are extremely pressed, and crushed to lenticular masses, showing all gradations between undular extinction and complete crushing and recrystallization to a finer aggregate. Besides, the newly formed quartz-feldspar mass between the grains is vigorously corroding the clastic grains and converting them to a finer aggregate. There is here an excellent illustration of the intimate connection of dynamical and chemical processes in the recrystallization of rocks.

A specimen from the New Eureka shaft, 200 feet down (343 Nevada County collection), of a similar black quartzitic sandstone occurring as a small mass in serpentine, shows in addition to the small quartzose veins a second set of fractures, crossing the former and filled with serpentine. The serpentine in places extends into the clastic feldspar and quartz grains, corroding them in such a way as to leave no doubt that a local serpentinization has been in progress.

The feldspathic pyrrhotite veins.—In the description of the Crown Point mine the occurrence of a very remarkable vein is mentioned, consisting of pyrrhotite and chalcopyrite with calcite and very little quartz. The sulphurets are said to contain some gold, while of free gold there is practically none. The pyrrhotite contains only a trace of nickel. This type is so radically different from the normal gold-quartz vein that it must be considered separately, and undoubtedly has been formed under differing conditions.

The specimens and slides of the black argillite from near this vein, and also from the New Eureka shaft, contain a number of small white veinlets, occasionally widening out to larger bunches of the same compact white material. Small grains and streaks of pyrrhotite and copper pyrites occur on all these seams, and in one instance a little zincblende is probably also present; beyond doubt, the vein near the Crown Point is only a larg r representative of this type.

Under the microscope the veins are seen to consist of quartz, calcite, and a plagioclastic feldspar, generally clouded and sometimes showing polysynthetic twinning. A small fragment of the feldspar was determined by Mr. George Steiger, by a qualitative analysis, as soda-lime feldspar approaching labradorite, the fusibility also agreeing with this result. In one veinlet (343 Nevada County collection) the feldspar occurs as small clouded prisms, between which lies clear quartz. This is the only occurrence of feldspar on mineral veins thus far known from this vicinity.[1] In the normal gold-quartz veins they have not thus far been found. The largest vein in the Crown Point mine shows no feldspar, but abundant light-green radial aggregate of chlorite, alike in the calcite, the quartz, and the pyrrhotite. This is also unknown from the normal quartz veins in this district.

Contact-metamorphic rocks.—For a distance of about 200 feet from the granodiorite contact dark-brown, fine-grained, quartzose, hornfels-like rocks appear, showing but little schistosity. In thin section a few larger clastic grains of feldspar and quartz lie in an extremely fine aggregate of the same minerals containing, besides, flakes of reddish-brown biotite and grains of magnetite and pyrrhotite. Organic matter is also present. In the smaller area south of South Wolf Creek normal

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[1] Mr. H. W. Turner has recognized albite forming with quartz in a shattered zone in an albite-porphyrite from the Shaw mine, Eldorado County. Am. Jour. Sci., 3d series, Vol. XLVII, pp. 470, 471.

sandstones appear in the eastern part, while the part adjoining the diabase is a fine-grained breccia of this same hornfels-like rock, sometimes with fragments of porphyrite, and on the whole very similar to the Banner Hill breccia. Some of the same characteristic quartz-augite mosaic occurs in it, the latter mineral being here identified beyond doubt. According to the best evidence available, the porphyrite is earlier than the granodiorite. It is possible that the porphyrite in forming this breccia—which must be considered as a contact breccia—has had a contact-metamorphic effect similar to that of the granodiorite, though probably less intense. In fact, there is some evidence pointing in the same direction from the Gold Flat diabase area (Nevada City sheet), for that rock often contains fragments of sedimentary rocks in which a similar development of secondary biotite has taken place.

Quartz-tourmaline rock.—In the porphyrite adjoining the granodiorite just west of the Scotia shaft are poorly exposed masses of a gray quartzitic rock with dark-gray spots and blotches. In thin section this rock consists of an allotriomorphic mosaic of quartz in which lie masses of greenish-gray tourmaline, sometimes with roughly radial structure starting from a center of darker tourmaline. The ends of the tourmaline crystals grow into the quartz grains. This rock is regarded as a contact-metamorphosed quartzite.

THE NORTH STAR AREA.

Adjoining the diabase there extends along the western margin of the Grass Valley tract an area of sedimentary rocks. The exposures, as a rule, are very obscure. The area appears to consist of large ledges of a grayish chert, separated by black, imperfectly fissile argillite, weathering gray and breaking in shelly fragments. The chert is in places almost pure hydrated silica, and contains little vugs with quartz crystals. It is very different from the siliceous argillite from Federal Loan.

Along the poorly exposed contacts with the granodiorite and diabase there is not much evidence of contact metamorphism. No special examination has been made as to the origin of the chert so abundant in this area, but it is suggested that it may be derived largely from limestone by a process of silicification, such as has often been noted from other places in the Gold Belt. This view is confirmed by the occurrence, on the top of the ridge northwest of North Star, of a bowl-shaped depression or pit several hundred feet in diameter, and which can not be explained except as a collapsed limestone cave. It is indicated on the map as "Devils Punch Bowl."

MARIPOSA FORMATION.

The Mariposa formation embraces the uppermost part of the Jurassic, and is composed chiefly of a series of clay-slates.

During the mapping of the area of the Smartsville sheet the existence of the Jurassic Mariposa slates, which south of Colfax are such a prominent feature of the foothill geology, was not recognized, nor have any fossils been found during the detailed examination in the rocks referred to this division. The evidence along other lines is, however, so strong that there can be no reasonable doubt that they are present.

The main belt of the Mariposa slates ends a short distance north of Colfax, being cut off by igneous rocks. The slates near Colfax are identified by the occurrence of several characteristic types of ammonites.[1] Lithologically they are characterized by black clay-slates and an abundant development of porphyrite-tuffs. About 7 miles north of Colfax a small streak of black tuffaceous clay-slates begins, and, extending under the andesite table, appears again a short distance east of the Washington mine on the headwaters of Wolf Creek. Here the series is quite extensive and consists largely of tuffaceous fissile slates, apparently gradually going over into porphyritic breccias.

A short distance northward the slates are replaced by porphyrite-breccia, but appear again in characteristic form near the Merrimac mine, on the dump of which fresh, black, tuffaceous slates are exposed, containing, as seen under the microscope, fragments of different kinds of porphyrites and of the brownish, siliceous argillite, entirely similar to that of Federal Loan, in an argillitic, very dense cement with much organic matter. The fragments do not show any evidence of considerable pressure. The slates near the mine contained much pyrite in sharp cubes.

The black clay-slates can be traced northward as a very narrow band, exposed in places by tunnels and ditches, until the excellent exposures along Deer Creek, mentioned above in the description of the Pittsburg porphyrite area, are reached. A short distance north of Deer Creek the belt ends. On the hill north of Deer Creek some siliceous argillite is exposed, besides the normal black, very fissile, and comparatively little altered clay-slate. A narrow isolated area of black clay-slate near Indian Flat has also been referred to this formation. Beyond this point the Mariposa slates have not been found.

The relatively unaltered character, the associated and interstratified porphyritic tuffs, and the occurrence of fragments of the older Calaveras formation are the evidences indicating beyond reasonable doubt that these rocks are younger than the Paleozoic formations. Throughout the area a steep or vertical dip prevails, and the schistosity coincides, approximately at least, with the stratification.

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[1] *Perisphinctes colfaxi* and *Olcostephanus lindgreni*. A. Hyatt, Trias and Jura in the Western States: Bull. Geol. Soc. Am., Vol. V, 1893, p. 395.

CHAPTER VI.

METAMORPHIC PROCESSES.

REMARKS ON METAMORPHISM.

Giving to the word metamorphism a somewhat wider sense than that in which it is commonly used, it may be defined as any transformation in the mineralogical composition or structure of a rock, with or without addition or subtraction of substance. This transformation can be brought about by different agencies and with widely differing results. The term metasomatism, or metasomatic action, is usually employed to designate a change in the chemical as well as the mineralogical composition, involving addition or subtraction of substance.

Restricting the wider definition of metamorphism, it is convenient to exclude from it the superficial weathering and disintegration, produced chiefly above the ground-water level by the action of atmospheric waters carrying oxygen and carbon dioxide. By this process there is not only a mineralogical transformation but the rock as such is destroyed. The products of this process are, besides soluble salts, chiefly silica, ferric hydrate, carbonates, and kaolin. Processes like cementation, or ordinary hardening of soft sedimentary rocks without extensive mineralogical or structural change, are likewise excluded.

Large metamorphosed areas are often spoken of as affected by regional metamorphism, a general term not designating the cause of the action. A large part of the Sierra Nevada may thus be said to have been subjected to regional metamorphism. The main cause, however, undoubtedly being orogenic pressure, the rocks are referred to as altered by dynamo-metamorphism. Strictly speaking, this term refers only to the purely dynamic processes of crushing and shearing by compressive stress distributed evenly through the rock or relieved along certain planes. A stretching action produced by a tensile stress has also been recognized by several investigators, but no decided evidence of its existence can be said to have been found during the examination of the rocks in this district.

While examples of dynamo-metamorphism without extensive mineralogical alteration occur, chemical forces are nearly always involved and very generally play a most important part, incited by the increase in temperature accompanying the pressure at points far below the surface and aided by the moisture of the rocks. It is not at all probable, however, that the heat during the dynamo-metamorphic processes in the Sierra Nevada has exceeded a few hundred degrees centigrade, and of fusion there is no indication at all. It is not necessary for the initiation of the recrystallizing action that the pressure should have been carried to a point at which the limits of cohesion were reached and schistose structure produced.

The process should perhaps more fittingly be designated *dynamo-chemical* metamorphism. It generally is characterized by a very moderate hydration and the formation of clear, fresh aggregates of mosaic structure. It usually produces a rock of finer texture than the original one. Igneous and sedimentary rocks are similarly affected, though the ultimate products usually differ. The chemical composition of the rock does not appear to be greatly altered by the process.

Dynamo-chemical metamorphism, best illustrated in this district by the Indian Flat amphibolite area and by the Grass Valley Calaveras slates area, ordinarily produces the following minerals: feldspar (probably very largely albite), quartz, hornblende, biotite, muscovite, chlorite (?), epidote, titanite, magnetite, pyrite, and pyrrhotite. The original feldspars are converted into albite, epidote, hornblende, quartz, and muscovite. The pyroxene alters to uralite and recrystallized hornblende, biotite, and epidote. The larger grains of clastic or porphyritic character are not only crushed but also resolved to secondary aggregates by a corrosively acting process of substitution, the new-formed minerals projecting into the primary grains.

Another and extremely prevalent form of metamorphism is apparent in certain rocks, such as the North Star and Osborne Hill diabase areas, which have certainly not been subjected to notable dynamic action. This process, characterized by the formation of confused mineral aggregates, not so much by clear secondary mosaics, and by a moderately extensive hydration, might provisionally be designated *common hydro-metamorphism*.[1] The process may evidently be begun and accomplished at a comparatively low temperature and depth under the influence of the moisture permeating the rocks below the groundwater level; the results imply that these were waters not oxidizing and which contained no great amount of carbon dioxide. As the depth increases, the character of the metamorphism will naturally change by reason of increasing temperature and static pressure.

The minerals formed are chlorite, serpentine, hornblende, epidote,[2] muscovite, probably also scapolite; further, magnetite, pyrite, and pyrrhotite; also zeolites. Secondary feldspars are apparently not formed in this process. The original feldspar alters to epidote, muscovite, and scapolite; the augite to hornblende, epidote, chlorite, and pyrite; ilmenite to titanite.

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[1] About equivalent to Roth's "complicirte Verwitterung."

[2] Epidote contains mainly ferric iron, and it is hardly possible that it can have been formed under strongly reducing influences. It is, however, not necessary to suppose that it must have been formed under oxidizing influences, for rocks ordinarily contain a considerable quantity of ferric oxide. Pyrite has often been observed embedded in epidote. It does not seem probable that it can be formed by surface weathering under ordinary temperature and pressure. Compare G. F. Becker, Mon. U. S. Geol. Survey, Vol. III, p. 211.

One of the principal differences between this process and dynamo-chemical metamorphism is the absence of the secondary feldspar and the mosaic structure. It is clear from the above that, as the mineral series of the two processes overlap, there must frequently be great difficulty experienced in distinguishing them, and the processes may in fact gradually merge into each other. Many of the products of the hydro-metamorphism have formerly been regarded as caused by surface decomposition or weathering.

Another form of hydro-chemical alteration in which hydration plays the most important part is serpentinization, by which certain basic igneous rocks rich in magnesia may, over large areas and to great depth, be transformed into serpentine. Being an essentially deep-seated process, serpentinization should certainly not be referred to weathering.

Still another form of chemical alteration is that effected by thermal ascending waters, and which may conveniently be designated *hydro-thermal metamorphism*. The results of this may vary considerably according to the composition of the waters. If gaseous compounds of sulphur associated with aqueous vapor are the chief agents, it should be referred to as *solfataric metamorphism.* Under certain conditions the hydro-thermal metamorphism may be almost indistinguishable from the ordinary hydro chemical process, which indeed is to be expected.

In the case of the gold-quartz veins here described, the waters were rich in carbon dioxide and sulphureted hydrogen, and the characteristic results of the intense metasomatic action are carbonates, muscovites, and pyrites.

Finally, by another transformation certain rocks may recrystallize when in close proximity to hot, intrusive, igneous magmas, principally those in a state of aqueous fusion. This is *contact metamorphism*, and its products are generally characterized by the same allotriomorphic, granular, fresh mosaic aggregate which characterizes the dynamo-chemical processes. The minerals formed are feldspar (chiefly albite), quartz, biotite, hornblende, pyroxene, andalusite, wollastonite, magnetite, pyrrhotite, and others. While the dynamo-chemical process tends to produce finer-grained aggregates than the original rock, contact metamorphism usually makes the texture coarser; this is illustrated by the contact near the Federal Loan mine. Nearly all sedimentary rocks and tuffs, as well as igneous rocks with a fine-grained groundmass, are subject to this alteration close to the contact, while coarser-grained igneous rocks appear to be but little affected; this is shown by the occurrence of fresh diabase close up to the granodiorite contacts.

The processes here enumerated are doubtless the most important ones, and each is in its way distinct and characteristic. Still, many places occur where it may be doubtful to which of these causes the effects observed are due, and especially difficult is the task when, as so often is the case, several kinds of metamorphism have successively affected the rocks. Among these doubtful cases must be counted the metamorphism of the Banner Hill breccias, with their abundant pyrrhotite and new-formed aggregates of quartz and a mineral strongly resembling pyroxene.

ALTERATION OF FELDSPAR IN THE ROCKS BY HYDRO-CHEMICAL PROCESSES.

The orthoclase is, as a rule, far more resistant than the plagioclase. When it is altered the product is generally a white sericitic muscovite. Alteration to calcite has not been observed except in the vicinity of the veins.

The secondary products in the soda-lime feldspars may be of different kinds, and, on the whole, those feldspars are very readily altered. Hornblende and epidote frequently develop in them; also, to some extent, biotite. The basic feldspars of the gabbros often break up into fine-grained saussuritic aggregates of zoisite and albite, but this appears to belong in the realm of the dynamo-chemical processes. By far more common, however, is an alteration to products which very much resemble sericite, and the presence of this or a closely allied mineral can, indeed, in many cases be proved, even when the orthoclase in the same slide is not attacked. This is certainly curious, but, as is well known, Lemberg has shown by his analyses of decomposed plagioclases that, as a matter of fact, the final product is often rich in potassium. In many other cases there is, however, considerable doubt whether the new-formed mineral really is sericite or not. Being in very small particles, it is difficult to determine. The refraction is low and the double refraction strong, though not so strong as would be expected in muscovite, and it is suggested that the resulting mineral might possibly be scapolite, a mineral known to occur as a product of alteration of feldspars. An extensive kaolinization of the feldspars has not been recognized, and probably does not occur below the zone of surface weathering.

The only extensive occurrence of a kaolin-like mineral is that in the rhyolitic tuffs mentioned below.

OCCURRENCE AND FORMATION OF IRON SULPHIDES IN THE ROCKS.

General features.—Too little attention has been paid to the occurrence and genesis of pyrite and pyrrhotite, so common in the rocks of many districts. For the study of mineral deposits this subject has the deepest interest, and it may therefore be of some value to summarize the results attained in regard to this during this investigation.

Pyrite and pyrrhotite can be formed in many different ways, in fact by any of the processes above enumerated, except by weathering under ordinary atmospheric influences.[1] And still the pyrite in the rocks,

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[1] It is recognized, of course, that the pyrite may be formed at the surface in the presence of strongly reducing influences.

when mentioned at all in descriptions, is often referred to as a product of weathering.[1]

Products of magmatic consolidation.—Pyrite and pyrrhotite may both be constituents of magmatic consolidation. Cogent proof of this is, of course, difficult to bring, and the fact is hardly yet quite universally recognized. The case recently described by Professor Vogt from Norway and the figures given here (figs. 2 and 3) from Grass Valley diabases leave, however, no room for doubt of primary origin. Besides the excellent occurrences in the Maryland and the North Star diabase area, these minerals have been so frequently found in other rocks, chiefly diabasic or porphyritic, under circumstances which strongly suggest, though not positively prove, primary origin, that the proposition may be confidently advanced that there are, as a rule, accessory primary constituents of the rock. As distinct traces of copper have also been found in one of the above-mentioned fresh rocks, it may be regarded as probable that chalcopyrite also occurs as a primary constituent.

Products of contact metamorphism.—Pyrrhotite has been recognized as an integral part of the allotriomorphic aggregates produced by contact metamorphism (Federal Loan area).

Products of dynamo-chemical metamorphism.—In the metamorphic rocks produced from igneous and sedimentary material pyrite and pyrrhotite have been observed as unquestionable constituents of the newly formed aggregates (Indian Flat amphibolite and Grass Valley quartzitic sandstone). Intergrowths of magnetite and pyrite are frequent. In certain amphibolitic schists in various parts of the Sierra Nevada large quantities of pyrite and chalcopyrite have been concentrated by these dynamo-chemical processes, forming the exact equivalents of the frequently described "fahlbands" from other parts of the world. It would seem suitable to reserve the designation fahlband for sulphides formed in schists by dynamo-chemical processes, thus not including in it schists altered by subsequent hydro-thermal action. These fahlbands sometimes appear to contain some silver and a little gold.

Products of common hydro-metamorphism.—Both pyrite and pyrrhotite have been developed abundantly in rocks subjected to hydro-metamorphism, and a little chalcopyrite has also been noted frequently. Developed in this way, the association with chlorite, as well as with epidote, appears characteristic. While the pyrite may occur as sharp crystals, it is more common to find it in anhedral grains often surrounded by chlorite rims. Pyrite and pyrrhotite often occur in intimate intergrowth with magnetite, and also filling seams and forming smaller segregated masses; pyrite and epidote are often found intergrown in this last-named manner.

Products of hydro-thermal processes.—Extremely abundant is pyrite in the metasomatic rocks accompanying the veins and formed under the

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[1] G. H. Williams, The greenstone schist areas of the Menominee and Marquette regions of Michigan: Bull. U. S. Geol. Survey No. 62, p. 214.

influence of vein solutions. Pyrrhotite never occurs, while arsenical pyrites may be formed. Magnetite apparently can not be formed under the conditions prevailing in this process. Idiomorphic form, as sharply defined cubes, is most common. A frequently available criterion for the identification of the pyrite of this process is the narrow rims of calcite or quartz surrounding the crystals. Large cubes often occur developed porphyritically in rocks which have not otherwise been subjected to very intense hydro-thermal processes, and do not disturb the groundmass or crystals in which they are embedded. The process must be regarded as entirely one of substitution, or dissolving of the original substance and depositing in its stead the pyrite. The pyrite developed in this way is generally confined to the vicinity of the vein. Large areas are not in this district affected by hydro-thermal processes.

The cause of formation is in this case undoubtedly the action of the sulphureted hydrogen or alkaline sulphides in the water on the silicates and oxides of iron in the rock.

In many cases, especially where several alterations have been superimposed, it is of course extremely difficult to designate the exact mode of origin of the pyrite and pyrrhotite, but in typical cases these five modes of formation may be clearly distinguished.

In the last case there has clearly been an addition of sulphur to the rock; in dynamo-chemical, contact metamorphic, and ordinary hydrochemical processes it is not clear that any such addition has taken place. It is, perhaps, rather to be regarded as probable that the sulphides have resulted from a concentration and recrystallization of the sulphur and the iron primarily contained both in sedimentary and igneous rocks. On this point it is, however, not easy to speak definitely. By preference pyrrhotite seems to form in the presence of very strong reducing influences.

WEATHERING.

Under the above name are included changes in cohesion and composition wrought in the rocks near the surface, chiefly by the decomposing and oxidizing action of the percolating surface waters, partly also by the change of temperature. Most intense at the surface, the action gradually decreases downward, and, in most cases, practically ceases when the level of the ground water is attained, which suggests that it is largely due to the carbon dioxide and oxygen contained in the surface waters. The processes result in two zones, more or less imperfectly separated: First, the deeper and more extensive part in which incipient decomposition and hydration produce a disintegration; the rock becomes soft and crumbling, but the chemical composition is not greatly altered.[1] Second, a surface zone of extreme decomposition and oxidation, resulting in the formation of a residuary soil.

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[1] This fact has been brought out recently by Prof. G. P. Merrill in his interesting studies on the decomposition of rocks: Bull. Geol. Soc. Am., Vol. VI, 1895, p. 321; Vol. VII, 1896, p. 349.

In the districts here described nearly all of the rocks are more or less deeply affected by those processes which may together be described by the not very apt expression "weathering." Deep-red residuary soil covers large areas, and the disintegration is sometimes found to extend to a depth of 200 feet. The granodiorite, the diabase, and the porphyrite, in some places also the andesite, are deeply affected, while the serpentine, for instance, is far more resistant to the weathering influences. The formation of such minerals as epidote and chlorite is here not considered as being due to the weathering, but to deep-seated processes. More detailed notes are found in the description of the different areas.

CHAPTER VII.

THE SUPERJACENT FORMATIONS.

While it is not intended to treat the Neocene deposits in detail in this paper, their general character may be briefly indicated.

AURIFEROUS GRAVELS.

The auriferous gravels proper, resting directly on the surface of the bed-rock series along the depressions of the Neocene rivers and creeks, consist, in the larger channels, of well-rounded pebbles of quartz and harder rocks of the bed-rock series, between which lies more or less sandy material. Although the gravel is largely quartzose, pebbles of other material are also plentiful. The size of the pebbles ranges from a fraction of an inch upward to cobblestones 6 or 8 inches in diameter, but the average size does not by far reach these dimensions. On the bed rock larger, partly rounded fragments occur occasionally. In the channels with granitic bed rock well-rounded bowlders several feet large are sometimes found in the bottom. In many of the tributary channels, such as the Harmony and the channel at the northwest end of Cement Hill, the gravel on the bed rock is partly angular and imperfectly washed. In the Harmony channel bodies and streaks of bluish clay alternate with streaks of gravel near the bed rock (fig. 6, p. 100). In the upper part of the gravel the pebbles are generally extremely well rounded and polished, and black, siliceous rocks make up a large portion of them. The deepest gravel has generally a dark-gray or bluish color, and contains much pyrite or marcasite, sometimes auriferous; streaks of reddish gravel also occur in the deeper parts of the mass. Nearer the surface the gravel is generally of reddish color. Fluviatile stratification is of extremely common occurrence. Very little gravel occurs in the Banner Hill area, though the lower parts of now largely eroded Neocene streams doubtless contained much of it. Very little gravel is found in the Grass Valley area also, and in the southern part of the Nevada City area. The largest accumulations are found north of Nevada City, in the deepest parts of the ancient stream system, where they reach a maximum thickness of 175 feet at the Manzanita hydraulic cut (fig. 4, p. 98). The banks of Cement Hill show 60 feet of well-washed gravel, with excellent fluviatile structure. Fig. 5 (p. 99) shows a nonconformity observed in the bluff.

RHYOLITIC TUFFS.

Above the auriferous gravels lie, in the deeper parts of the depressions, a series of light-colored or white clayey or sandy rocks, more or less perfectly consolidated, and commonly described as pipeclay and sand. These are largely rhyolitic tuffs, more or less pure. Certain of the beds consist nearly exclusively of minute fragments of glass, while others are so admixed with mainly granitic detritus as to nearly mask their tuffaceous character. The fragments, both of glass and of granitic minerals, are generally very sharp and angular. Besides, bodies of gravel are also included in the tuffaceous series, and, on the whole, it is impossible to draw a distinct line between the auriferous gravels and the rhyolitic tuffs. On the southern face of Cement Hill the line between the two formations is fairly sharp, separating 60 feet of gravel from over 200 feet of rhyolitic tuff. A little rhyolitic material is found in the sands of the main channels down to a distance of 40 feet, or even less, from the bed rock. The occurrence of the rhyolitic tuff is practically confined to the northern part of the Banner Hill and Nevada City tracts.

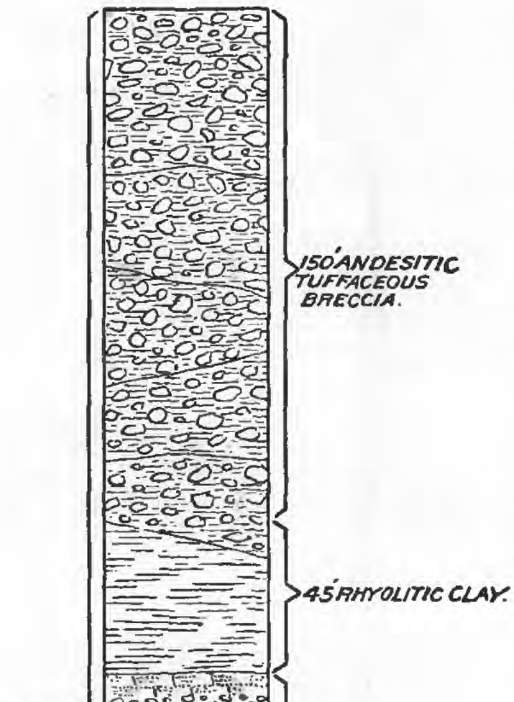

FIG. 4.—Section of superjacent formations at Manzanita mine, Nevada City.

The composition of several tuffs and sandstones is shown by the table on the next page; the partial analyses were made by Dr. H. N. Stokes.

It is apparent that the purest tuff has very nearly the composition of a rhyolite. Grains and flakes of a brownish translucent mineral, with faint double refraction, are abundantly developed, especially in the rocks poor in alkalis. This is undoubtedly the same kaolin mineral recognized by Mr. H. W. Turner in his Ione sandstone.[1]

[1] Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1894, p. 464.

Table of partial analyses of clays, sandstones, and rhyolitic tuffs.

	2 N. C.	5 N. C.	7 N. C.	8 N. C.	10 N. C.	14 N. C.
SiO_2	69.54	67.46	67.94	69.06	75.65	62.70
Al_2O_3, Fe_2O_3	21.14	18.60	21.69	15.97	17.33	16.97
CaO	.30	1.18	.45	1.03	.29	.13
K_2O	1.26	1.76	1.64	5.00	.42	.32
Na_2O	.25	3.41	.20	1.38	.20	.13
	92.49	92.41	91.92	92.44	93.81	80.25

2 N. C.: Odin mine, 2 feet above bed rock. Sandy clay containing no rhyolite fragments.
5 N. C.: 800 feet south of Sugarloaf reservoir. Yellowish sandstone with rhyolite fragments; 100 feet above bed rock.
7 N. C.: West Harmony drift mine, 4 feet above bed rock. Sandy clay; no rhyolite fragments.
8 N. C.: 850 feet west of West Harmony incline. Pure rhyolite tuff.
10 N. C.: Manzanita pit, 10 feet above bed rock. White sandstone; a few rhyolite fragments.
14 N. C.: Hydraulic pit, west of Odin mine. Crumbling white sandstone; a few rhyolite fragments.

At the Cement Hill diggings, in the northwest corner of the Nevada City area, sandstones and gravel occur cemented by an almost pure, yellowish opal.

ANDESITIC TUFFS.

It has already been mentioned that the high, gently sloping ridges of these districts are covered by andesitic flows, and their general character as tuffs and tuffaceous breccias has also been described. As a

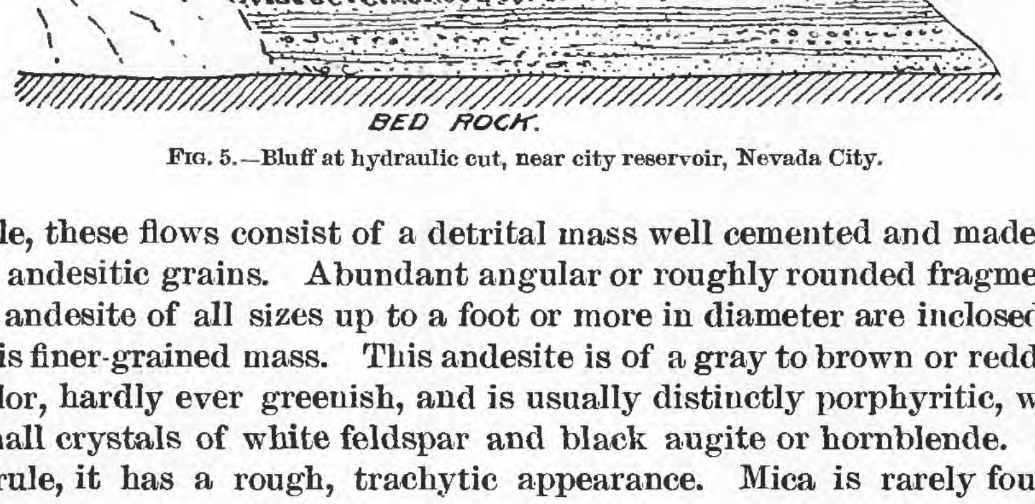

FIG. 5.—Bluff at hydraulic cut, near city reservoir, Nevada City.

rule, these flows consist of a detrital mass well cemented and made up of andesitic grains. Abundant angular or roughly rounded fragments of andesite of all sizes up to a foot or more in diameter are inclosed in this finer-grained mass. This andesite is of a gray to brown or reddish color, hardly ever greenish, and is usually distinctly porphyritic, with small crystals of white feldspar and black augite or hornblende. As a rule, it has a rough, trachytic appearance. Mica is rarely found.

Pyroxene (both augite and hypersthene) is almost invariably present. Black basaltic hornblende frequently occurs with the pyroxene, and usually in larger crystals. The groundmass is partly glassy, or of a very fine grained, holocrystalline structure. The thickness of the volcanic flows ranges from 400 feet in the Banner Hill district to about 200 feet in the Nevada City district. The easily disintegrating cement renders the exposures unsatisfactory, and a deep, reddish soil usually covers the tops of the ridges. This disintegration, and the tendency of the decomposed material and residual andesitic bowlders to slide downhill, often make the contacts with the underlying formations obscure and difficult to trace. Good exposures are found in the vicinity of the Harmony gravel mines. The best exposure, though practically inaccessible, is in the bluff of the Manzanita hydraulic pit north of Nevada City. Resting unconformably on the sloping surface of the white clays and sands, there are here at least four separate flows of andesitic tuff, each 20 to 30 feet thick and separated by irregular, worn

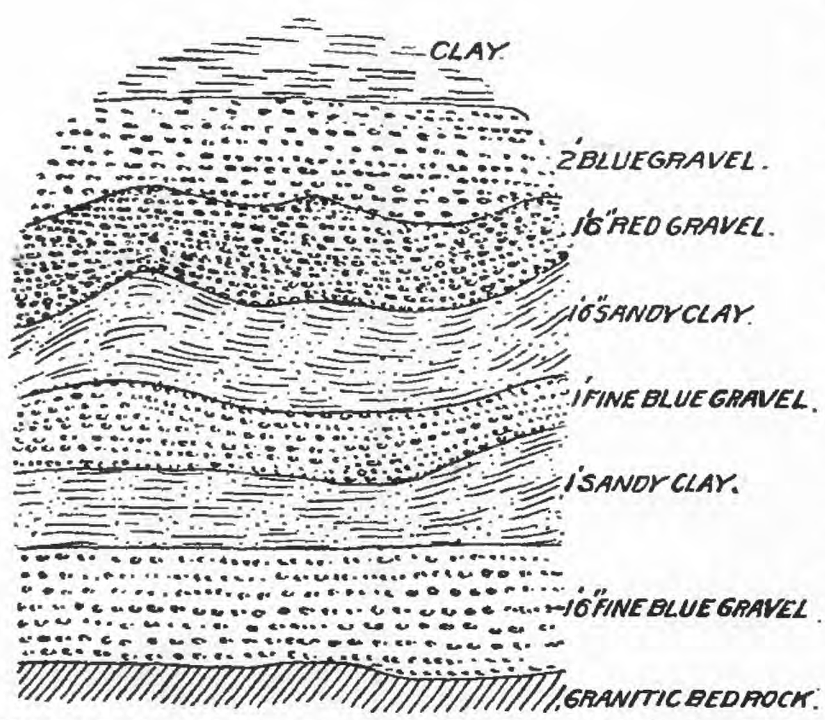

FIG. 6.—Section of breast of workings, West Harmony drift mine, 300 feet east of main drift.

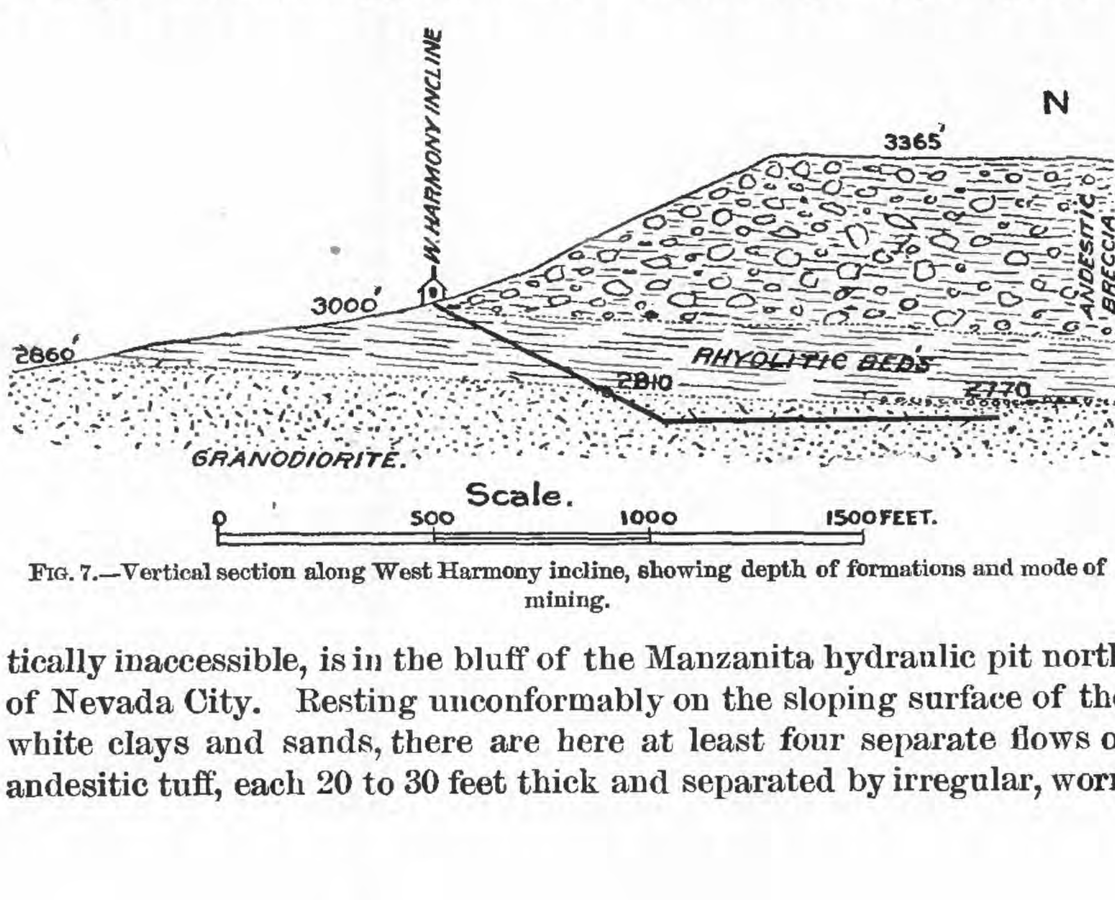

FIG. 7.—Vertical section along West Harmony incline, showing depth of formations and mode of mining.

surfaces. The amount of angular andesitic bowlders is not constant, and some flows consist entirely of the fine, detrital, cementing tuff. Of such character are the tuffs overlying the clays and gravels exposed in the hydraulic pit just north of Grass Valley.

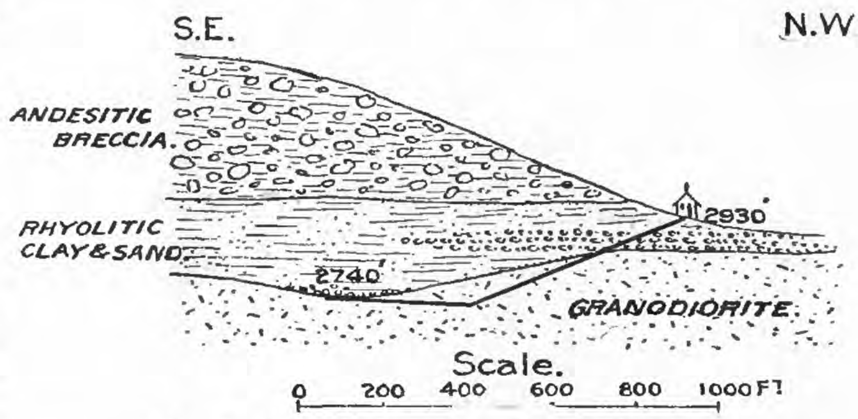

FIG. 8.—Vertical section along Yosemite incline.

ALLUVIUM.

The alluvial deposits are of small extent, and consist principally of a few gravel flats along Deer Creek, Little Deer Creek, and Wolf Creek. Many of these bodies of gravel are formed of débris from hydraulic gravel mines.

Alluvial sands and clays have accumulated in several swampy flats to the south and southeast of Nevada City, and also to some extent near the race-track. The largest alluvial deposits lie in Deer Creek below the Providence mine, and consist of well-washed gravel of quartz and metamorphic rocks, with some sand. They are made up largely of the débris from the extensive hydraulic mines just north of Nevada City, which had their principal outlet through the first gulch emptying into Woods Ravine from the east. In the Grass Valley district extensive flats of sand and clay occur on both branches of Wolf Creek above the city, and smaller gravel flats are found at intervals along the creek below the city. In the southwestern part of the district there are at the headwaters of the gulches a number of shallow alluvial flats of sand and clay, usually of a marshy character. The largest is found south of the North Star mine.

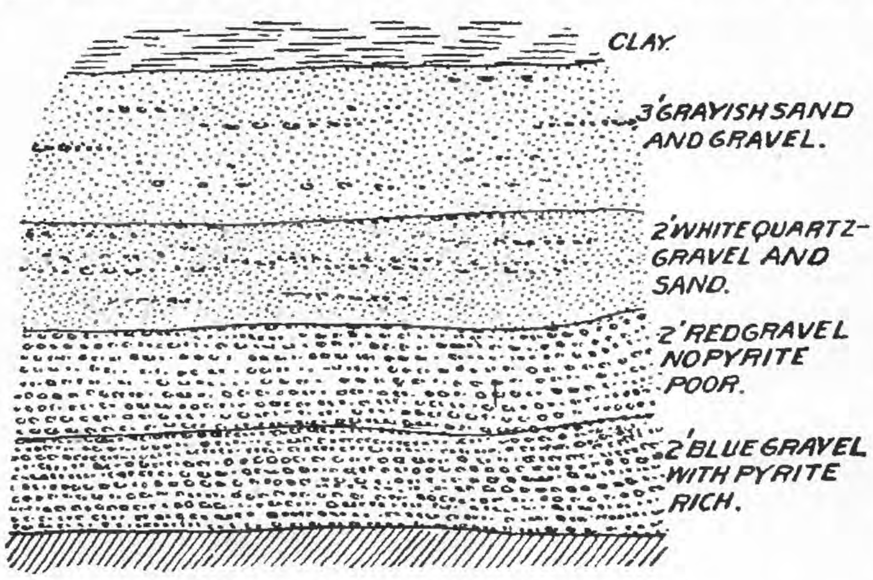

FIG. 9.—Section in workings of Odin drift mine.

CHAPTER VIII.

GEOLOGICAL HISTORY.

RÉSUMÉ OF HISTORY OF THE BED-ROCK SERIES.

With the knowledge acquired by the preceding more detailed study, the history of the bed-rock series may now be briefly reviewed.

The sedimentary series of the Calaveras formation are, without much doubt, the oldest rocks in the district. They comprise several subgroups of different character, and these may well be of considerably differing age. All that can be said definitely is that they antedate the Mariposa formation, and it is probable that they all are Paleozoic. No volcanic tuffs are found in these beds, though Paleozoic eruptives are known in this formation from other parts of the Sierra Nevada.

The formation was folded and strongly compressed long before the igneous rocks now associated with it had made their appearance. In the formation there is absolutely no evidence of synclines or anticlines, the compression having evidently reduced the series to practically parallel, extremely sharp folds, upon which a schistosity has generally been superimposed, in most cases apparently coinciding with the bedding. Subsequent intrusions have broken up this once-connected formation, and fragments of it are now contained in the later igneous rocks. The schistosity in the Calaveras formation of Nevada City and Grass Valley does not, then, necessarily correspond to the lines of disturbance in the bed-rock series developed subsequent to the granitic intrusion.

Then, after a considerable interval, probably followed the intrusions of the diorite-gabbro-pyroxenite group. The relations of this group to the other rocks is one of the doubtful points. On one hand, there seems to be an intimate relation between the granodiorite and the above-mentioned group, indicated by the occurrence of what may be transitions, and it is well known that the granodiorite may, close to the contact, pass into more basic allied rocks. Further, dike-like masses of serpentine and gabbro occur in the diabase and porphyrite, and even in the Mariposa formation (short distance above the Washington mine, upper Wolf Creek). On the other hand, there is clear evidence, from certain well-exposed places along the granodiorite-diorite contact, that the former is an intrusion into the latter, and there is excellent evidence afforded by dikes that the diabase and porphyrite are later than the diorite-gabbro group. On the whole, the probability is that the diorite-gabbro group of this district is older than both the granodiorite and the diabase and porphyrite. It is probably of the same age as the gabbros and diorites of the foothills of Nevada County from Indian Springs northward, in which also dikes of diabase and allied porphyrites occur.

No very satisfactory evidence has been obtained as to the sequence within the diorite-gabbro group, but as far as it goes it seems to indicate that the basic rocks were the older and the more acid diorites the later parts of the intrusion. It is indeed not impossible that various parts of the gabbro and serpentine may be of different age, for it is well known that dikes of these rocks in other parts of the Sierra cut the Mariposa formation. In the text of the folio of the special sheets[1] it has been stated that probably none of the igneous rocks are older than the Mariposa formation. It is, however, necessary to admit that this is a very doubtful point in the case of the diorite-gabbro group. If the dikes of diabase and porphyrites occurring in it are contemporaneous with those similar rocks accompanying the Mariposa formation, it is certain that the rocks of the diorite-gabbro group at this vicinity were intruded before the Mariposa slates were deposited.

After this the eruptions and intrusions of diabase and allied porphyrites took place. This was not a local phenomenon, but similar igneous action occurred all along the foothills of the Sierra Nevada, resulting in the building up of volcanoes along the shore line to a height of many thousand feet above the present surface, only the interior parts and roots of which are now visible. During the earlier part of this widespread igneous action the late Jurassic Mariposa beds were laid down, and the tuffaceous rocks of this age contain abundant fragments of porphyritic rocks of an effusive type. The materials extruded during this period of intense volcanic action include, as is to be expected in a series of large volcanoes, rocks of both intrusive and effusive types. Basic rocks prevail, ranging in composition from medium-grained diabase to augite and hornblende porphyrites with cryptocrystalline groundmass; in the latter it is quite possible that some glass was once present, which is now devitrified; an extensive devitrification can certainly not be recognized. Rocks of moderate acidity occur to small extent in this igneous series, and are younger than the basic predominating rock, while very acid rocks or alkaline rocks are absent. Many of the effusive rocks correspond closely in mineralogical and chemical composition to the modern andesites.

After the deposition of the Mariposa beds and the close of the accompanying igneous activity, followed the important post-Mariposa orogenic disturbance. The Mariposa beds and tuffs were folded, compressed, and welded with the already compressed Calaveras formation. The igneous rocks were over large areas crushed and rendered schistose by intense dynamo-chemical metamorphism, while other areas escaped the pressure, which was chiefly concentrated along certain lines and belts of shearing. Within this period falls the formation of the Indian Flat and the Brunswick amphibolite belts.

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[1] Geologic Atlas of the United States, Folio No. 29, Nevada City (Nevada City, Grass Valley, Banner Hill), Cal., 1896.

Now followed the last and farthest-reaching phase of igneous activity, in the form of the intrusion of enormous masses or batholites of granodiorite in the range, tearing asunder the older rocks and bending and twisting the older schist masses.

The intrusion must have taken place under great depth of overlying but now eroded rocks. Plainly shown as the fact is by geological investigation, the actual mechanical process almost surpasses our conception. In spite of the great pressure that must have been exerted by the intruding masses of granodiorite, it is not apparent that this pressure has produced any schistose structure on the surrounding rocks; the schistosity usually antedates the granitic intrusion, though in some cases it has been produced subsequent to it.

In this connection one fact deserves to be emphasized: There is absolutely no evidence of fusion of the surrounding masses accompanying these gigantic intrusions of molten magma; it should be expected in the Sierra Nevada if anywhere, but except very locally it is not found. This, as well as many other facts, throws great doubt upon the theory of genesis of igneous rocks by the fusion of sediments, a theory not without its adherents at the present day. Smaller masses of more basic material are frequently found along the contact of the granodiorite, showing evidence of earlier consolidation. Contact metamorphism affected many of the surrounding rocks to a width of up to a thousand feet; still larger contact-metamorphic zones are found adjoining the large granite areas of the higher Sierra.

The dynamo-metamorphic action continued after the intrusion of the granodiorite, but with less intensity, and evidences of this post-granitic disturbance are not noted in the special areas. Intrusions of small amounts of very acid, alkaline, and also of more basic magmas (aplites, quartz-porphyries, and lamprophyric dike rocks), followed the main intrusion of granodiorite and may be regarded as forms of differentiation of that magma.

The last phase of the history of the bed-rock series is the formation by compressive stresses of an extensive series of joint systems and fissure systems of differing directions, generally not coinciding with the old lines of dynamic disturbance. Along these joints and fissures ascending thermal waters deposited the ores and altered the country rock. Thus the hydrothermal metamorphism was the latest alteration to which the rocks have been subjected. Series of joints or sheeting parallel to the quartz veins are illustrated in Pl. III, opposite, and fig. 10 (p. 183).

The close of the granodioritic intrusion falls between the end of the Jurassic and the Chico Cretaceous, probably in the beginning of the Cretaceous period. At that time the Sierra Nevada must have formed a mountain range of imposing extent and elevation, in which the rocks now exposed at the surface were deeply buried.

SHEETED ZONE IN GRANODIORITE, MAIN STREET, GRASS VALLEY.

Dips toward the west.

HISTORY OF THE SUPERJACENT SERIES.

THE GAP IN THE RECORD.

After the time of granitic intrusions and formation of quartz veins followed a period, including the latter part of the Cretaceous and the beginning of the Tertiary, from which no geological records are preserved, at least not in this vicinity. But there are indications elsewhere that the range during the whole time was a land area, and that the mountains of the early Cretaceous were subjected to long degradation, during which they were reduced at least to a condition of only moderate relief. Probably at the close of the Cretaceous the first break along the eastern margin took place, by which the Sierra Nevada was differentiated from the interior plateau and began to attain its present characteristic form. Erosion, invigorated, wore down broad valleys in the old plateau, and at some time during the beginning of the Neocene period the relative relief was such as the cast of the lavas covering it has largely preserved for our investigation to-day.

THE NEOCENE BED-ROCK SURFACE.

The Sierra Nevada was, in this latitude, a range of moderate height and relief, with a chain of prominent foothills, made up of the Jurassic lavas, with middle slopes characterized by broad river valleys and moderate relief, made up of the Calaveras slates, and with higher and more rugged summits made up of granitic rocks. Traces of the old Cretaceous plateau or the pre-Neocene peneplain are visible at intervals in the relief.

Excellent opportunities are offered in this district to study more closely the old Neocene surface. The areas covered by the Neocene deposits are numerous. The elevations along the contact lines and the data available from the underground exploration of the auriferous channels afford sufficient materials from which to construct a contour map of the Neocene surface (Pl. II). There are, of course, many spaces which must be filled in by suggestions obtained from adjacent areas, and many details may be incorrect, but it is very certain that the plate gives a generally correct conception of the Neocene topography. Of course, the map is affected by any subsequent deformation or tilting that the old surface may have undergone. Parts of the area where the data are insufficient have been left blank. The general features of the contour map show a prominent relief, but much less cut and scored by deep creeks and ravines than the modern topography. Banner Hill, the Town Talk Ridge, and Osborne Hill were then, as now, salient points of the topography. These eminences rose from several hundred to over a thousand feet above the deepest depressions. Banner Hill was, however, an unusually prominent point in this part of the comparatively gentle middle slopes of the Neocene Sierra, its hard siliceous breccias strongly resisting disintegration. North of Banner Hill a prominent, high ridge of siliceous argillite divided the watershed of the Nevada basin from the main Yuba River, flowing from Scotts Flat northward toward Blue Tent and North Columbia.

West of Town Talk the drainage was clearly westward, down toward Rough and Ready. The Grass Valley tract in its northern part was drained by the Alta channel, heading northeast of Osborne Hill. There is no evidence that the channel continued eastward to Buena Vista slide, as stated in a previous publication.[1] Good proof of this is furnished by the fact that the rhyolitic tuff from the main Yuba channel also flooded the Buena Vista channel and the depression southwest of the Washington mine, but did not overflow into the basin of the Alta channel.

In the Nevada City district it is clear that the main depression was in the vicinity of Nevada City, for there the accumulations of gravel, sand, and clay are deepest and the elevations of the bed rock lowest. Up toward the highlands of Town Talk and Banner Hill the depth of the material mentioned grows less, and at a certain elevation the andesitic tuff rests directly on the bed rock. In the lower part of the basin the curious feature is presented of an almost continuous channel 4 miles long and practically level.

From Pecks diggings, at the head of Native American Ravine, at the northwest corner of the Nevada City tract, where the elevation of lowest bed rock is 2,650 or 2,660 feet, there is without doubt a continuous channel to the Empire shaft, with a lowest bed-rock elevation of 2,660 feet. Again, there is no reasonable doubt that the channel is continuous to the great hydraulic pits northwest of Nevada City, and here again the bed-rock elevation is 2,650 feet, even sinking to 2,625 feet in the vicinity of the old Merrifield mine. From here the lowest channel continues eastward over the exposed bed rock of the hydraulic ground, at elevations ranging from 2,630 to 2,640 feet. Again, at the southern end of the Manzanita channel the elevation is 2,645 feet. From the Manzanita pit the rich gravel on the bed rock, a few feet thick, has been drifted on up to the Odin mine, at which place the lowest bed rock is 2,655 feet. From the Odin incline the channel has been extensively prospected in the belief that it connected with the Harmony channel under the lava hill. The channel is here wider and the gravel of lower grade than farther south. At the Howe cut, where the channel emerges from under the ridge, the lowest bed rock has an elevation of 2,650 feet, though at the inner part of the cut a harder, granitic bed-rock ledge rises to an elevation of 2,670 feet. Such local inequalities are often met with in the old channels. There is thus no decided evidence to be derived from the grades as to the direction of the old channel.

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[1] Bull. Geol. Soc. Am., Vol. IV, p. 269. The channel at Buena Vista probably graded toward the east, to the main Yuba River.

Other facts show, however, that the Cement Hill channel, in the first place, must have flowed from the northwest to the southeast. First among them is the evidence from the gravel. At Peck's diggings there is only a few feet of imperfectly washed quartz gravel overlain by the clays and sandstones of the rhyolitic series, which here attain a depth of only 70 feet. At the diggings northwest of Nevada City the gravel is 60 feet deep, extremely well washed, and covered by from 150 to 200 feet of light-colored rhyolitic beds. This alone shows plainly enough that the direction of the channel was southeasterly. Regarding the other part of the channel, it has generally been supposed that it came down from the north, and that, bending about near Nevada City, its now eroded lower course followed the present valley of Deer Creek westward toward Rough and Ready. At the first glance this not only seems plausible but actually sustained by the grade of the channels, but there are very cogent arguments against such a supposition. In the first place, as in this vicinity the period of erosion between the rhyolitic beds and the andesite is insignificant, it should confidently be expected that some of the rhyolitic material would be found in the neighborhood of Randolph House and Rough and Ready, southwest of Nevada City, where fragments of channels are preserved. No such beds are, however, found there, the andesitic tuff resting directly on the bed rock or the gravel. On the other hand, presuming that the Manzanita channel did come from the north, we are confronted with the fact that the outlet of the Harmony channel at Laney's tunnel is somewhat lower than the bed rock at Howe cut, so that, on this supposition, in no way—the outlet being to the eastward of Howe cut—could any connection then have existed between these two channels. That the Harmony channel is continued toward the northwest to join the old Yuba River is clearly shown by the lower deposits at Round Mountain and the still lower fragment of channel preserved at Montezuma Hill. There would thus be no room left for headwaters of such a large channel as the Manzanita, on the supposition that it came from the north. Furthermore, the Manzanita channel was extremely rich in coarse gold. To the north of it are no quartz veins worth mentioning, while immediately to the south of it are the rich vein systems of Nevada City. On the west, toward the Providence mine, begin a series of much harder rocks, resistant to weathering, and which would easily form a barrier, just as the slate and diabase of Banner Hill, Federal Loan, and Town Talk still form barriers to the east and south.

The Manzanita channel then formed the central drainage of a flat depression in the easily eroded granodiorite, surrounded on east, south, and west by an amphitheater of rising hills. This drainage is indeed the most natural one to be expected in a vicinity where the tendency to transverse drainage is not so strongly developed as on the tilted plain of the modern Sierra Nevada. It has been shown in a former paper[1]

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[1] Bull. Geol. Soc. Am., Vol. IV, p. 296.

that the grades of the Neocene river courses clearly indicate that such a tilting has taken place along an axis parallel to the crest of the Sierras, and that the amount of it, though not exactly regular over the whole slope, was 60 or 70 feet per mile as a maximum. Applying this principle to the Neocene drainage system of Nevada City, the difficulties are overcome, and the drainage becomes a very natural one.

The Cement Hill channel, with a direction from northwest to southeast, had then, before the tilting, a grade of 60 to 70 feet to the mile. The partly eroded channel between the western end of the big hydraulic pits and the Manzanita pit, which now has a slight grade of 20 feet westward, had before the tilting a moderate grade of about 50 feet per mile eastward. The channel between the Manzanita and the Howe cut, now practically level (excepting the hard projecting ledge at the latter cut), and which runs nearly due north, had before the tilting a slight grade northward of about 20 feet per mile.

From the Howe cut (elevation 2,650) to the lowest bed rock at Round Mountain,[1] 2½ miles due north, or 1 mile east of the line of tilting (elevation 2,625), there is a present grade of 10 feet per mile, which before the tilting was 30 feet per mile.

From Round Mountain to the lowest bed rock at Montezuma Hill (2,356 feet elevation, according to Pettee in Whitney's Auriferous Gravels), a distance of 2¾ miles in a direction nearly due west, there is now a grade of 100 feet per mile, which before the tilting would have been 30 feet per mile.

From Montezuma Hill down to French Corral, along Shady Creek and the present Yuba River, the only way which the Manzanita River could have followed, is a distance of 6 miles, with a present grade of 100 feet to the mile.

The Harmony channel must have joined the Manzanita a mile or two north of the Howe cut. The Harmony, coming down in a westerly direction, has now a very steep grade of about 150 feet per mile from the East Harmony to Laney's tunnel. Before the tilting it had a grade of about 80 feet per mile. East of the East Harmony the grade increases rapidly as the high ridge of siliceous argillite is approached. It has been held by many that the Harmony channel continues an indefinite distance up the ridge. This is impossible, as only a few miles eastward the deep Yuba channel, from South Flat to Blue Tent, crosses the ridge. The Harmony channel is well up toward headwaters, and under the Harmony ridge divides up into several branches. The subangular character of its gravel and the steep grades prove that the divide is not far distant. Its richness is not because of its being a main and important channel, but because of its crossing a system of rich quartz veins. It is barely possible that a deep gorge cuts through the ridge of siliceous rock and extends as far east as the Fountain Head, but it must be characterized as highly improbable. The vicinity

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[1] See Geologic Atlas of the United States, Folio No. 18, Smartsville, Cal.

of the Fountain Head probably drained toward the main Yuba River eastward. There is, of course, no reason why auriferous channels should not be found on the east as well as on the west side of the divide. There is also a difference in elevation between the surfaces of the rhyolitic flows of from 200 to 300 feet between the vicinity of Cold Spring and Fountain Head. Such great difference would scarcely exist if there had been a communication between the two localities.

Considering the subsequent tilting, the Neocene bed-rock surface would originally have had a less sharp westward slope than is indicated on the map. Banner Hill, instead of rising to a height of 1,250 feet above the Manzanita channel, as now, would have had a height of only 1,050 feet above that point.

THE AURIFEROUS GRAVELS.

Having thus examined the surface on which the Neocene deposits rested, it remains to outline briefly the events that caused its burial under Neocene sedimentary and igneous deposits. At a period immediately preceding the volcanic eruptions of rhyolite and andesite the accumulations of gravel were not deep at any part of this area, located well up on the ridges dividing the main drainage lines. Along these main rivers, and principally along the great longitudinal valley of the Yuba from You Bet up to North Columbia, masses of gravel several hundred feet in depth had accumulated. One (though not the only) of the principal causes of this exceptionally heavy gravel mass is to be found in the fact that the Yuba River, flowing on the middle slopes in a broad and open valley, had to turn and force its way through the foothill range of Jurassic lavas in a relatively deep and narrow canyon, almost as deep as that of to-day and well shown by the present relations at Smartsville. This foothill range acted as a barrier, restraining the gravel masses in the open valleys of the middle slopes. In the Nevada City area the prevolcanic gravels reached the greatest depths along the Manzanita channel, and it is doubtful whether they have at any place exceeded a thickness of 40 feet. Rhyolitic fragments are found at that elevation above the bed rock, and even lower. It is doubtful whether the gravels, 60 feet thick, of the hydraulic pits northwest of the city are antevolcanic; the gravel is different from that generally found in the deepest parts of the Neocene channels, and has more the appearance of the extremely well-washed "black gravel" which appears at the higher elevation and which belongs in the rhyolitic period. Outside of the main drainage channel there was only a few feet of gravel on the bed rock along the streams, and in by far the greatest number of exposures the andesite or rhyolite rests directly on the bed rock. There is no reason to believe that the antevolcanic gravel in this vicinity antedates the Neocene period.

THE VOLCANIC FLOWS.

Such were the conditions when eruptions of enormous masses of rhyolitic tuffs began on the headwaters of the Neocene Yuba River. Their general character has been referred to above. It is probable that they were erupted as mud-flows, emerging from the crater mingled with much water, and that there was not only one but a long series of flows, in the intervals between which the older flows were to some extent worked over by the running water and interstratified with clay, sand, and gravels of local origin. These rhyolitic flows, 200 to 300 feet thick, are well exposed at Alta, on the Central Pacific Railroad, and at Chalk Bluff, near You Bet. At the latter place an extensive Neocene flora was collected by Mr. C. D. Voy and examined by Prof. L. Lesquereux.[1] The rhyolitic flows of Nevada City are the exact stratigraphic equivalent of the rhyolite tuff of Chalk Bluffs, and there can thus be no doubt about their age. Leaves similar to those of Chalk Bluffs occur at many places in the vicinity of the Manzanita channel, and with some trouble it may well be possible to obtain a good collection.

The tuffs are well exposed at Quaker Hill and Scotts Flat, farther down the Neocene river, and again on the north side of the Washington ridge at Blue Tent, at which place they are several hundred feet thick, the top stratum attaining an elevation of 3,000 feet. Near the place where the upper North Bloomfield road crosses Rock Creek, there was a low gap in the ridge between the main Yuba and the Nevada City basin; through this gap the rhyolitic tuffs poured into the granitic basin. It appears as if north of Blue Tent there was an obstacle, such as a narrowing valley, forcing the masses over the low divide in the adjacent drainage. The first flows found their way down into the Harmony and lower Manzanita channels, causing a damming of the latter, which again, of course, produced accumulation of sand and gravels in the upper part about Nevada City, and to this damming it is believed the heavy gravels of the Manzanita cut and Cement Hill are due. Subsequent flows found their way down to Round Mountain and Montezuma Hill, obstructing the channels to still greater extent. At last the whole of the lower part of the Nevada City basin became filled. The elevations of the top layers now range from 3,100 feet on the eastern side of the basin to 2,740 feet at the northwestern corner of the Nevada City tract, a distance of 5 miles from east to west. It will be noticed that on the supposition of a tilting of 70 feet per mile the surface would once, over this distance, have been approximately level, and about at the same level as the top stratum of the rhyolitic tuff at Blue Tent.

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[1] The exact locality seems a matter of some doubt. It is not now accessible, having been covered by hydraulic débris. Professor Whitney states that the matrix is a rhyolitic tuff, but in the few specimens I examined, by the courtesy of Prof. A. C. Lawson, of Berkeley, the rhyolitic character is not clearly apparent under the microscope. At the locality I was told that the leaves were found in clay just below the white tuff and at the top of the extensive bench gravels of You Bet, several hundred feet above the bottom of the deepest channel.

The rhyolitic tuffs did not reach the southern and highest part of the Nevada City basin, nor did they overflow into the Town Talk or Grass Valley channel. To the east of the Neocene divide, rising along the eastern margin of the Grass Valley tract, the rhyolitic flows again appear, having reached there from the vicinity of You Bet. The divide was, however, just high enough to prevent this overflowing into the Alta channel.

As may be seen by tracing the contacts of andesite and rhyolite, the surface was not even, but subjected to some eroding action in the interval between the two eruptions; but it was not extensive enough to produce any marked change. In fact, those intervolcanic channels, cutting far down into the rhyolite, and even into the underlying bed rock, which are so characteristic of the vicinity of Forest Hill, Placerville, and Mokelumne Hill in the drainage of the Neocene American and Mokelumne rivers, are practically absent on the main Yuba, although on the headwaters of the North Yuba, near Forest City, they appear again. This is evidently caused by a differing time interval between the two eruptions; in this vicinity the first andesitic flow from the Lola and Castle Peak volcanoes followed closely after the last eruption of rhyolitic tuff.

During the latter part of the rhyolitic period many divides were flooded and the drainage was partly changed. The great Neocene orogenic movement of the Sierra probably took place between the rhyolitic and the andesitic eruptions, as is evidenced by the intensely eroding character of the cement channels or intervolcanic channels. A tilting took place, elevating the eastern part of the range most strongly and the western part but little. Flows of andesite tuffs, emerging from the craters as a mud, poured down the flanks of the Sierra in rapid succession, obliterating the old drainage and flooding many of the divides, Banner Hill and Osborne Hill alone emerging from the desolate lava plateau in this vicinity. On this inclined lava plain the rivers had to select new courses, in general differing considerably from the old ones. The present drainage was developed, characterized more than the Neocene by a transverse direction of the rivers.

CHAPTER IX.

THE ORES.

GENERAL FEATURES OF THE GOLD-QUARTZ VEINS.

Although gold is very widely distributed over the Sierra Nevada in veins and placer mines, there is no other part of it which shows such a concentration of valuable deposits within a narrowly circumscribed area as occurs in the districts here discussed. Almost the only form which the primary deposits of the bed-rock series present in this locality is that of quartz veins, consisting of fissures of somewhat different though closely related character, filled more or less continuously by quartz carrying native gold and auriferous metallic sulphides. These fissures, belonging to several systems, are usually traceable on the surface by means of the often harder, projecting quartz croppings, and attain a maximum length of a few miles; by far the most, however, can be traced only a few hundred or a thousand feet. In some localities the extremely decomposed surface rock and the narrow character of the veins render the tracing of the outcrop a most difficult undertaking, in which the miner's pan is an indispensable adjunct, for all quartz in these districts contains gold, though it may be present in very small quantities.

There is in some quarters a widespread belief that the veins of Nevada City and Grass Valley are in some way connected with the long, continuous linked veins of the Mother lode. This is a mistake, for the last branches of that vein system are found about 20 miles south of Grass Valley, and, moreover, the veins of Grass Valley and Nevada City differ considerably in their general character from the veins of the Mother lode.

With some notable exceptions they are narrow and produce a comparatively high grade of ore. They contain, as a rule, a much larger per cent of gold than of silver (by weight); the free gold is the most important constituent in the depth as well as on the surface, but besides there is a variable amount of gold and silver in the sulphurets.[1] The strike varies to all points of the compass; the dip is usually flat and also equally variable in direction. With all these different directions it is, however, easy to distinguish two main systems, north-south and

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[1] This word, extensively used in the mining regions, has been adopted in this report to designate all the metallic minerals occurring on the gold veins excepting the native gold, thus including the simple and compound sulphides and arsenides as well as tellurides.

east-west veins. In the former system the veins may dip either east or west; in the latter, north or south.

The mines of the Grass Valley district have been and are especially productive; next in production follows the Nevada City district, and the Banner Hill district comes third. A large proportion of the production has been derived from a few prominent veins, such as the Eureka-Idaho, Rocky Bar, North Star, Empire, and Providence.

A type of veins different from the ordinary gold-quartz veins, though not of much practical importance, occurs in Grass Valley, and is characterized by pyrrhotite and chalcopyrite in a gangue of calcite, quartz, and feldspar. (See Crown Point mine, detailed description, Chapter XVI.)

OTHER DEPOSITS.

Though the quartz veins in their different forms constitute the only primary gold deposits of the districts under consideration, there are in Nevada County a few somewhat differing types of deposits of which brief mention may be made. The Pine Hill gold deposit,[1] about 10 miles south of Grass Valley, is characterized by a zone of intense thermal decomposition resulting in the formation of kaolin, a mineral practically unknown from Nevada City and Grass Valley, as well as masses of secondary quartz resulting from the decomposition of the porphyrite in the vicinity. There are abundant veins of barite, also unknown from the mentioned districts, and a little pyrite. The finely distributed gold contains much silver. This deposit has doubtless been formed by chemical action widely different from that characterizing the normal veins.

From Sweetland, a town on the ridge between the Middle and South Yuba, there extends down to the Yuba River, northwest of Nevada City, a narrow belt of fine-grained, amphibolitic slates altered to sericitic schists containing abundant pyrite. This pyrite carries gold, which is set free by surface decomposition; the rock has been mined and milled at the Boss mine near Sweetland. The streak is well exposed on the Yuba River. This process again would, on the whole, seem to have been identical with that by which the normal veins have been formed, and the only difference is that, in the case of the Boss schists, practically no quartz has been deposited, the solutions penetrating the schists, which were crushed to some extent, but without any notable open spaces.

Another streak along which impregnation of auriferous iron pyrites has taken place extends in the acid granodiorite and allied rocks from near French Corral across the Yuba River at the mouth of Owl Creek.[2] Here, too, the decomposed rock has been mined and milled, though of very low grade. The mineralogical character of this zone appears different; there is no extreme thermal decomposition of the

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[1] Am. Jour. Sci., Vol. XLII, 1892, p. 92.

[2] Cf. Geologic Atlas of the United States, Folio No. 18, Smartsville, Cal.

rock, which is impregnated with pyrite in grains and along seams, and there is apparently no notable development of sericite. Instead, the pyrite appears to be connected with epidote, which would show a closer connection of this deposit with the general metamorphism than with the vein deposits in which epidote is unknown.

MINERALOGY OF THE VEINS.

GANGUE MINERALS.

Quartz.—The quartz occurring on the veins is generally massive, of a milky-white color and a luster between glassy and fatty. A grayish, very glassy quartz is considered an indication of poor ore. This milky-white quartz is, as thin sections show, usually made up of large, very irregular grains, occasionally with partly developed crystal faces. Sometimes the crystal faces show more plainly, and from this there are transitions to the well-known interlocking comb structure. This, however, in its typical form, is not very common. In the Osborne Hill and Centennial mines a radial structure of the massive quartz is sometimes noted. Fluid inclusions are abundant, though small, and usually irregularly distributed. Well-developed crystals are not common, and are chiefly found in small cavities or vugs in the massive quartz. Certain veins, such as the Granite Hill, are of very drusy character, long, imperfect crystals coating the walls and radiating from fragments of the country rock. All of the ore minerals subsequently to be described occur as inclusions in the quartz.

Opal and chalcedonite.—In several mines small quantities of a brownish chalcedonite, extremely fine grained in structure, occur with the quartz. Often it is of such deep-brown color as to be hardly translucent in thin section. It is found as irregular masses in the quartz, or as veinlets cutting through it, or again, as at the Osborne Hill mine, filling cavities and surrounding projecting quartz crystals. Gold directly embedded in the chalcedonite has been found on the 600-foot level in the Rush and Laton shoot, Empire mine, and 140 feet below the surface in the Hudson Bay shaft. Professor Blake reports "grayish-blue or white opal, probably allied to cacholong," from the North Star mine,[1] while Professor Silliman mentions chalcedony from Massachusetts Hill, Allison Ranch, Kate Hayes, and Eureka mines.[2]

Calcite.—Calcite occurs in small quantities on every vein in the district. In the decomposed country rock adjoining the vein it is very abundant, though always in massive granular form. In the quartz it occurs frequently as small particles not easily visible to the naked eye; occasionally, also, as larger masses, of white color, breaking into good-sized cleavage pieces—for instance, in the Spanish mine and in the South Idaho. Crystallized calcite is occasionally found in cavities in

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[1] Pacific Railroad Report, Vol. V. p. 268.

[2] Am. Jour. Sci., Vol. XLIV, 1867, p. 236.

the quartz; small scalenohedrons (R3) were noted from the Providence mine; larger, short, and thick crystals, combination of $-\frac{1}{2}R$ and a steep scalenohedron, with several subordinate faces, occur in the Empire mine, twentieth level.

The calcite in the wall rock of the vein generally contains some iron and magnesium.

Magnesite occurs nearly pure, as a product of alteration of serpentine, in the Idaho and Maryland mines.

Sericite.—This is a form of muscovite, or white mica, extremely common as microscopic aggregates in the altered wall rock, but the individual foils are hardly ever visible to the naked eye. The white color and greasy feel of many of the altered wall rocks are due to this mineral.

Mariposite.—This is a bright-green, foliated mineral closely allied to muscovite. The green color is due to a small percentage of chromium. It occurs in small quantities in magnesite or quartz in the Idaho-Maryland mine. A little of it was also noted from the Providence mine. Generally it appears to be a product of alteration of serpentine.[1] There appears to be no good reason for separating it from fuchsite or chromiferous muscovite.

Scheelite.—This mineral, a tungstate of calcium, is stated to have occurred in considerable quantities in the foot wall of a mine on Howard Hill, Grass Valley.[2] This is interesting, if authentic, being the only occurrence of tungsten in the district.

ORE MINERALS.

Native gold.—Metallic gold is contained in all quartz veins of this region in smaller or larger quantities. The most common form in which the gold appears is that of minute flakes and particles, as a rule not visible to the naked eye. To this there are, however, numerous exceptions. In several mines a large part of the gold is in the form of larger leaves, sheets, or masses. The Grass Valley veins carry, as a rule, more coarse gold than those of the Nevada City tract. A small vein will usually carry more coarse gold than a large one, and in certain seam mines the gold may occasionally appear as a sheet filling the entire seam, with but little quartz. Massachusetts Hill and Gold Hill, Grass Valley, were noted for the heavy masses of gold extracted from their veins. A specimen from the Crown Point mine, Grass Valley, contained in a 3 or 4 inch vein of quartz and calcite in serpentine at least $200 in heavy, massive gold. The coarse gold is rarely crystallized, and the forms, where occurring, are rude and distorted. Beautiful leaf gold sometimes occurs in cavities coated with quartz crystals; for instance, in the Granite Hill vein, Grass Valley. Mr. Melville Atwood states[3] that in 1859, in the mine of North Gold Hill, he

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[1] For analysis, by Hillebrand, see H. W. Turner's article on the gold ores of California, in Am. Jour. Sci., Vol. XLIX, May, 1895.

[2] Fourth Ann. Rept. State Mineralogist of California, p. 353.

[3] Eighth Ann. Rept. State Mineralogist, p. 774.

took out a pocket of many thousand dollars' worth of gold, all in leaf-shape form, with beautiful quartz crystals, and they were all embedded in a decomposed ferruginous matter. The gold is chiefly contained in the quartz; only once, in a specimen from the South Idaho mine, was it noted in calcite. Occasionally, but very rarely, visible particles of it occur in the altered wall rock adjoining the veins.

A close association of the gold with the patches of sulphides occurring in the quartz is often noted, and sections will often reveal larger and smaller irregular particles of gold contained in the galena, iron pyrites, arsenical pyrites, zincblende, or tellurides.[1] (Pl. V, fig. *c*.) Generally, however, the sulphurets are auriferous even when it is impossible to detect any metallic gold in them with the microscope. It is probable that the gold is here, as in the quartz, in a metallic state, distributed in extremely minute particles.

All quartz gold contains, as is well known, alloyed silver. In the majority of the veins of this district the fineness ranges from 800 to 860. In the Willow Valley east-west veins the amalgamated bullion is less pure, generally about 750 fine. In Canada Hill the gold averages 730. In the Lecompton and the Federal Loan mines the bullion has been observed as low as 650 and 670. This should probably not be taken to indicate that the native gold contains 350 parts of silver, for the ore may have contained easily amalgamated, rich silver minerals, and arsenic and antimony may also be contained in the bullion. In fact, a specimen from the Beckman vein, at Canada Hill, of which the amalgamated bullion is only 750 fine, contained abundant, easily visible, bright-yellow gold equally distributed in the quartz, galena, and blende.

The North Star vein, as well as the veins of Massachusetts Hill and Gold Hill, contains high-grade gold, averaging 850 and sometimes reaching 875.[2] The Seven-thirty mine reports gold 950 fine, which is very unusual. The Merrifield and Providence veins contain gold averaging 800 fine. In the Osborne Hill veins, which carry much arsenical pyrites, the gold averages 760 to 775. In the Empire mine, belonging to the same system, the fineness is about 800. In the Eureka-Idaho vein it is 848.

Electrum, a pale-colored alloy of gold and silver, with more than 25 per cent of the latter metal, has not been noted.

Gold amalgam.—Mr. C. Hesse, superintendent of the Odin drift mine, obtained from samples of fresh undisturbed gravel, taken on the bed rock of the channel and washed in the pan, a number of small but well-rounded, white, metallic grains, associated with the gold, and which proved to be gold amalgam. Its occurrence and appearance admitted of but one explanation—that it had the same origin as the gold and once occurred in a quartz vein of the vicinity. Some of the flat, rounded grains consisted, as shown under the microscope, partly of gold, partly of amalgam.

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[1] Gold in pyrites and galena noted from the Omaha mine; gold in arsenopyrite noted from the Betsy mine; gold in zincblende noted from the Mayflower and Grant mines; gold in altaite noted from the Providence mine.

[2] Compare Fourth Ann. Rept. State Mineralogist, p. 222.

Tellurium minerals.—Tellurides are probably more common than has been suspected, but it is only rarely that they occur in quantities large enough to be mineralogically determined.

A telluride of silver, presumably *hessite*, lead-gray, soft, and somewhat sectile, was identified by Dr. W. F. Hillebrand in a specimen from the Nevada City mine, occurring with pyrite, galena, and native gold.

Altaite, a telluride of lead and silver, tin-white, with a yellowish tinge and sectile, was also identified by Dr. Hillebrand from the Providence mine. It occurred in considerable quantities as a bunch in the Ural vein of that mine, in the stopes between the 600-foot and 1,200-foot levels. It was associated with quartz, pyrite, galena, and abundant native gold, the latter intergrown with the tellurium mineral.

In testing samples of the concentrated sulphurets from several mines for tellurium, a negative result was usually obtained. The element was found in small quantities in the concentrates of the Nevada City and Providence mines. A remarkably large percentage of tellurium was found in the Idaho-Maryland concentrates, amounting to 0.03 per cent; there have been no tellurides noticed thus far in the ores of that mine. Tellurium is also said to occur in the ore of the Charonnat or Canada Hill mine.

Tetradymite, or telluride of bismuth, is doubtfully reported from the Murchie mine,[1] and Mr. J. J. Ott, of Nevada City, states that a tellurium mineral was certainly found at that mine. It is worthy of note in this connection that a small quantity of bismuth was found in the concentrates from the Providence mine.

Pyrite.—This mineral occurs on practically every vein in the district, both in the quartz and in the altered country rock. In the quartz the mineral is usually found in massive form, intergrown, without recognizable succession, with other metallic minerals. Imperfect crystal forms are often recognized, though well-developed crystals occurring in cavities are rather uncommon. The forms shown are always a combination of cube and pentagonal dodecahedron. In the altered wall rocks sharp, though usually small, crystals are extremely common, and the cubical form predominates. Excellent and sharp cubical crystals up to 1 cm. in diameter occur in a soft chloritic rock on the dump of a shaft on the Kentucky claim, some distance east of the Maryland. Pyrite is the most abundant of the "sulphurets" in the quartz veins, and generally makes up from 80 to 90 per cent of the concentrates.

Small masses of pyrite, intergrown with epidote and magnetite, occur in diabase in the tunnel on the Star Placer mine, west bank of Wolf Creek just above the Omaha mine.

Marcasite.—This mineral, the orthorhombic form of iron disulphide, does not appear to occur in the quartz veins. A very pale yellow pyritic mineral found on the dump of a tunnel 1,800 feet south of the Golden Treasure mine was at first thought to be marcasite, and a statement to this effect was made in a paper on the "Characteristic

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[1] See Eighth Rept. State Mineralogist.

features of California gold-quartz veins."[1] Professor Penfield, to whom the specimen was shown, considered it, however, as pyrite with a marked octahedral parting, and Professor Pirsson kindly measured the fragments, finding angles closely approaching those of the octahedron. Such an octahedral parting has not been previously observed in pyrite.

In the blue gravel from the bottom of the Neocene channels concretions of iron disulphide often occur, sometimes cementing quartz grains and pebbles. From the pale color and strong tendency to decomposition exhibited, it is probable that this is marcasite.

Pyrrhotite.—This mineral, also known as magnetic pyrite, occurs sparingly, but not, so far as known, on any of the normal gold-quartz veins in this district. It is contained as a primary constituent in certain diabases of Grass Valley, and as a secondary mineral impregnating many metamorphosed rocks (in hornfels near the Federal Loan, in porphyrite-breccia on Banner Hill). Larger masses of it were found in a seam a short distance north of the Crown Point mine. It is here associated with chalcopyrite, pyrite, and calcite, with very little quartz. According to Dr. Hillebrand, it contains only a trace of nickel.

Chalcopyrite.—Nearly all of the quartz veins contain this mineral, but only in small quantities. It rarely makes up more than 3 per cent of the sulphurets in the quartz. The Providence, Champion, and Nevada City mines, and especially the Idaho-Maryland, carry the largest quantities of it. It is very rarely crystallized. A little chalcopyrite is also found disseminated in certain metamorphosed diabases and porphyrites.

Galena.—This is almost universally present in quantities about equal to the chalcopyrite. It forms grains and irregular masses in the quartz, and is rarely if ever found crystallized. It is frequently rich in gold, and is always considered a "good indication."

Sphalerite (*zincblende*).—This mineral is extremely common, and occurs in the quartz on almost every vein in the district. The Providence concentrated sulphurets contain 1.6 per cent of zincblende, and in the Beckman vein, Canada Hill, the percentage is still greater. The Idaho-Maryland vein, on the other hand, contains extremely little of this mineral. The zincblende is usually black, with a greenish tinge. In the Alpine tunnel, Canada Hill, a pale-yellow variety occurs, together with the former. In the Beckman vein and in the Osborne Hill mine the blende is reddish-brown, and often very rich in gold.

Arsenopyrite.—This mineral is very common, but somewhat irregularly distributed. It occurs both in the quartz and in the adjoining altered country rock, and seems, in fact, to prefer the latter. When in larger accumulations it is mostly massive, but it exhibits a great tendency to form minute and extremely sharp crystals when occurring disseminated in the country rock or in the quartz. Beautiful, though small, crystals, long and slender and formed by a combination of prism and base, are found in the Osborne Hill vein. Most of the veins in the Banner Hill tract contain abundant arsenopyrite, the Federal Loan

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[1] Bull. Geol. Soc. Am., Vol. VI, p. 231.

leading, with about 18 per cent in the concentrated sulphurets. On the other hand, the Providence-Champion-Nevada City complex of veins carries very little of this mineral, a sample of Providence concentrates containing only 0.012 per cent. In the Grass Valley tract the percentage of arsenopyrite in the veins is usually very small, excepting the Osborne Hill system, which, from the Orleans mine south, carries considerable quantities of it. The veins of Forest Springs, 4 miles south of Grass Valley, also carry much arsenopyrite.

Pyrargyrite, stephanite, and argentite.—These rich silver minerals have been identified in a specimen from the Allison Ranch mine, in the United States National Museum (No. 14967). Besides these minerals, the specimen contains much pyrite, chalcopyrite, and galena. Pyrargyrite has also been found in the Central mine, south of Banner Hill. The relatively large quantity of silver found in the concentrates of certain other mines, for example, the Providence, Champion, and North Banner, indicates the possibility of rich silver minerals occurring in a finely divided state in them.

Tetrahedrite (fahlerz).—On a vertical cross-vein cutting across the Osborne Hill vein, near the shaft, on the fourth and fifth levels, a heavy mass of tetrahedrite was found carrying 1 per cent of silver. The mineral was associated with yellow zincblende and chalcopyrite. It is also reported from the North Banner mine,[1] and probably occurs in small quantities in many other mines in the Banner Hill and Willow Valley districts.

Molybdenite.—In the California gold-quartz mines this mineral is by no means uncommon. It has been found, inclosed in quartz, in the North Banner mine; in a nameless vein, nearly barren of gold, in the Mayflower ground; and in the Merrifield and Ural veins, at the Providence, Champion, and Nevada City mines. It usually forms bunches, and is apparently not intimately associated with the other sulphurets; it is not known to be auriferous. When occurring abundantly it makes the pulp in the battery black and slimy, and interferes with the amalgamation on the plates. It is easily mistaken for graphite.

Cinnabar.—While no cinnabar has yet been found in any quartz vein of the district, the fact deserves mention that according to Mr. J. J. Ott, of Nevada City, grains and pebbles of this mineral were at one time found in the sluice boxes of the Manzanita hydraulic mine. Taken in connection with the above-mentioned occurrence of amalgam, it may be considered certain that one or several of the veins in the Nevada City tract contained quicksilver. The association of quicksilver and gold has frequently been noted in the Gold Belt.

PRODUCTS OF SURFACE DECOMPOSITION.

Limonite, or brown iron ore, is common in the decomposed quartz of the upper levels in most of the mines. As is well known, it is a result of the surface decomposition of pyrite.

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[1] Eighth Ann. Rept. State Mineralogist, p. 421.

A *hydrous sulphate of aluminum* occurs as a deposit from spring waters in the Providence drain tunnel, in part colored blue by copper.

Azurite and *malachite* result occasionally from the decomposition of chalcopyrite.

MINERALS NOT CONNECTED WITH THE QUARTZ VEINS.

Copper.—Metallic copper in small rounded crystals was also found in the gravel of the Odin mine. The crystal form indicates that the copper was probably precipitated from solution by reducing influences in the blue gravel and the crystals formed in the gravel. Whitney[1] mentions native copper occurring in the Tertiary channels.

Magnetite.—A small deposit of magnetite with some quartz is found in the diabase, near the granodiorite contact, 4,000 feet east of the Omaha mine, in Diamond Creek. The exact nature and extent have not been ascertained. There are within the foothills of the Sierra Nevada several similar deposits, some of large size, and always occurring in diabase or slate, close to the contact with the intrusive rock. These occurrences are probably in genetical connection with the intrusive rock and possibly formed by contact-metamorphic action.

Scattered fragments of magnetite are also found near the dry reservoir 1,700 feet east of the railroad station at Grass Valley, and not far from the granodiorite contact.

Magnetite also occurs with epidote and pyrite, as probably segregated masses leached from the surrounding rock, in the tunnel of the Star placer mine, 1,650 feet north of the Omaha mine.

Earthy manganese ore (*pyrolusite* or *wad*) occurs often in small fissures in the granodiorite near the surface. It was especially noted in the vicinity of the North Banner mine.

A similar manganese mineral was found as a concretion in the West Harmony drift mine, cementing grains of quartz.

Garnet.—This mineral is evidently very rare in this district. Brownish massive garnet was noticed, probably as a product of contact metamorphism, in a specimen of amphibolitic rock collected in a little gold by the road, 1,600 feet west of the North Banner mill.

Wollastonite.—A specimen of wollastonite in hornfels was found on the Old Banner dump. This mineral also is undoubtedly due to contact metamorphism.

Chabazite.—At the tunnel of the Star placer mine mentioned above crystals of chabazite were found coating small fissures in an altered diabase, filled with epidote and pyrite. The crystals are several millimeters in diameter, colorless, and of the well-known pseudo-cubical form.

THE MINERAL WATERS ON THE VEINS.

General features.—The ordinary mine water contains only a small amount of dissolved substances, and is evidently meteoric water of the superficial circulation. In a few instances, however, strong ascending

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[1] Auriferous Gravels, p. 366.

springs are found on the quartz veins. These springs, though neither very rich in dissolved materials nor of a temperature differing from that of the inclosing rocks, form a deposit at the point where they issue, and their composition is of interest as in some degree indicating the nature of the springs to which, in all probability, the veins owe their origin. Two such ascending springs were noted and their waters and deposits examined.

The Federal Loan mine.—The first is in the 400-foot level of the Federal Loan mine, about 400 feet east of the shaft. The water issues from a crack in the foot wall about 5 feet up from the bottom of the drift, the quantity being about 2 gallons per minute. A considerable quantity of yellowish-white, slimy deposit was, at the time of my first visit, formed on the wall for a distance of 2 or 3 feet below the place where the water issued; the deposit did not seem to form on the bottom of the drift. At a second visit, when the water was collected, the work had been resumed in the drift, the face of which was only a few feet from the spring, and the deposit had been swept away. Mr. George A. Treadwell, of Nevada City, had previously collected a bottle of the substance, which he kindly placed at my disposal. An unmistakable odor of sulphureted hydrogen was noted in the vicinity of the spring. A sample of 2 liters of the water was filtered and bottled in the mine.

The Mountaineer mine.—The second locality is in the Mountaineer mine (Nevada City sheet), on a hanging-wall vein called the Black Prince, about 170 feet east of the main fissure. The spring appears in the foot wall on the 400-foot level, south of the shaft, tastes strongly of iron, and forms a heavy yellowish-brown deposit. There was no odor of H_2S in the vicinity of the spring.

The waters were analyzed by Dr. W. F. Hillebrand, with the following results:

[Parts per million (grams per ton).]

	Federal Loan.	Black Prince.
SiO_2	32.70	41.40
Cl	3.16	3.10
S	1.10	....
SO_4	7.70	7.80
CO_3	141.80	146.60
Pb	Trace.	Trace?
As	None.	Trace?
Fe_2O_3	4.20	1.80
Al_2O_3		
Mn	.27	1.90
Ca	33.60	44.35
Mg	5.70	3.35
K	1.00	1.60
Na	13.40	13.70
H_2 (for bicarbonates)	4.60	4.70
	249.23	270.30

NOTE.—Organic matter present in small quantity in both waters.

Dr. Hillebrand remarks on these waters as follows:

> Both waters showed an alkaline reaction, and that from Federal Loan gave also a test for sulphides in solution after filtration. The Federal Loan water contained a small amount of black flocculent deposit, chiefly silica colored black by iron sulphide, so far as could be made out. The Black Prince water contained a large amount of similar black deposit containing much iron sulphide and, perhaps, ferric hydrate. No test for soluble sulphides resulted definitely in this sample, but there appeared to be a little hyposulphite (thiosulphate) in both waters. Hydrogen sulphide was not present in either. Since the waters were reported to be clear when bottled, it seems probable that the formation of soluble and precipitated sulphides may have been due to the reducing action on the sulphates of the corks, especially since the waters had been bottled many months, and the surface of the corks was thoroughly blackened. In view of the great uncertainty as to whether the present condition represented in important essentials that at the time of bottling, a very exhaustive or thorough analysis seemed unnecessary. It is to be noted that although the deposit formed by the water contains much arsenic it could not with certainty be detected in 2 liters of the water.

The waters are remarkably similar in composition, and may be characterized as weak mineral waters, chiefly distinguished by their percentage of silica and carbonates. There is, roughly speaking, from 33 to 41 parts per million of silica present, 175 to 226 parts of bicarbonates of calcium, magnesium, and sodium, and 12 to 14 parts of sulphates. Sodium is present in far larger quantities than potassium. Chlorides occur only in very minute quantity. Of carbonic acid there is hardly enough present to form bicarbonates with the bases. Hydrogen sulphide was certainly present in small quantities in the Federal Loan water at the time of bottling, although subsequent reactions probably masked its presence.

The composition of the deposit from the Federal Loan water is, according to Dr. Hillebrand, as follows, in rough approximation:

	Per cent.
$CaCO_3$ $MgCO_3$	10.8
Mn (as MnO_2)	.6
As (as As_2O_5)	1.3
Fe (as Fe_2O with little Al_2O_3)	23.3
Insoluble and silica	18.4
SO_3	.5
Pb	Trace.
Organic matter and water	34.9
	99.8

Dr. Hillebrand makes the following remarks on this analysis:

> The bottle was filled with a black slimy matter emitting a disgusting odor of organic decomposition. The cork was forced out with ease by imprisoned gas, chiefly consisting of CO_2 and CH_4. The slime was said to have been white when

collected; the subsequently developed black color is due to iron sulphide. Aside from organic matter and water the deposit is essentially ferric oxide with a little arseniate, calcium carbonate with a little magnesium carbonate, and manganese as MnO_2, besides gelatinous silica and fragments of minerals. Owing to reduction of sulphates with bottling and the presence of vegetable organisms, an accurate analysis could have no value, and the amount at disposal was also too small.

The presence of lead and arsenic in this deposit is of interest. The organic matter was abundant, and consisted of long, stringy fibers, evidently an algous growth, such as is so often noted at the mouths of mineral springs.

The deposit from the Black Prince was of brown color and in qualitative composition chiefly ferric hydrate with a little calcium carbonate and much less magnesium carbonate, also silica and insoluble matter and much manganese in a peroxidized condition. There was also a decided trace of molybdenum. No arsenic, copper, lead (?), nickel, or aluminum was detected, and very little sulphuric acid. Some organic matter was present.

The Providence mine.—A deposit found in the drain tunnel of the Providence mine, 800 feet from the mouth, is of quite different character. When dried, it formed dirty white masses of all degrees of fineness, from coarse lumps to an impalpable powder; some of it has a decided greenish tinge. Selected greenish pieces were analyzed by Dr. Hillebrand, with the following result:

	Per cent.
SiO_2	8.31
Al_2O_3	37.57
Fe_2O_3	.44
CaO	.12
MgO	Trace.
CuO	.57
Mo	Trace.
Na_2O	.17
So_3	9.51
H_2O	42.98
	99.67

The water was determined as follows:

	Per cent.
Over H_2SO_4	15.16
At 110° C	8.39
Below redness	19.03
Blast	.40
	42.98

A general sample showed essentially the same composition, and contained, besides, MnO_2 in black grains. Some organic matter was also present.

The substance appears to be a mixture of a hydrous aluminous silicate and sulphate, and probably results from the leaching of pyritous ore by surface waters.

THE ORES.

GENERAL CHARACTER.

There are, in general, two classes of gold-quartz veins, between which, however, no distinct line of demarcation exists. The first embraces those veins in which the gold is nearly exclusively connected with the sulphides and is not easily removed from them by simple amalgamation and in which free gold is found only in the upper decomposed zones; in these veins there is usually also much silver. The other class, to which the veins here described belong, carry an ore of which the principal value lies in the free gold, the relative amount of which shows no diminution in depth once the surface zone of decomposition is traversed. The gold and the auriferous sulphides, some of which are always present, are embedded in a predominant quartz gangue and constitute almost exclusively the pay ore. The country rock adjoining the veins has in most cases been subjected to a more or less complete replacement by carbonates, sericite, and sulphides, but this replaced country rock is here, if not barren of gold, at least very poor. In certain deposits the quartz is distributed in minute seams and streaks in the decomposed country rock instead of forming a continuous, thicker sheet; in such cases the whole may be mined and milled, but the pay will generally be found to be concentrated in these narrow seams. In isolated cases the altered country rock may contain a sufficient quantity of gold to be treated as an ore. Instances also occur where a large quartz vein is nearly barren but the seams in the adjoining altered rock are rich in gold.

THE GOLD.

As stated before, the gold is, speaking generally, in a finely divided condition and scarcely visible to the naked eye, and it is a well-known fact that sometimes a notable quantity of it is carried away suspended with the finest slimes from the mill, even in the overflow from the settling tanks, if such are used. Much of the gold in the narrow Grass Valley mines is, however, quite coarse; in several mines, as the North Star and the Empire, bunches of quartz containing coarser gold are found in the pay shoots, generally carrying fine gold. The intimate relation between the gold and the sulphurets is emphasized above and illustrated on Pl. V, fig. *a*.

THE SULPHURETS.

Quantity.—The sulphurets generally make 2 to 3 per cent of the ore. In the Willow Valley district there is quite generally a stronger percentage, ranging from 4 to 6 per cent. The same conditions obtain in the Banner Hill and Mayflower group of veins. The veins in the vicinity of the Pittsburg and Gold Tunnel group of veins, except the Pennsylvania, carry a less amount. In the Providence-Champion group the percentage is high, ranging from 4 to 6 per cent, but the same veins in their northward extension carry less again. The Idaho system of east-west veins carry little sulphurets, as do also the Empire-Osborne Hill system and the W. Y. O. D., the percentage ranging from three-fourths of 1 to 3 per cent. The Eureka-Idaho vein shows, on the whole, the smallest percentage, ranging from three-fourths of 1 to 2 per cent. The Massachusetts Hill and Granite Hill veins, as well as the North Star, carry from 2¾ to 3 or 4 per cent. The Omaha system carries about 4 per cent.

In comparing these data no definite law can be deduced as to the percentage of sulphurets in different country rock. The largest percentage is found in granodiorite, in certain veins in the sedimentary areas, or on the contact of both formations; a medium to small percentage occurs in diabase and porphyrite and in serpentine. Numerous exceptions make this rule of doubtful value. Some veins of the Mayflower system in slate and some mines in granodiorite, such as the Gold Tunnel and California, contain comparatively little sulphurets.

Equally doubtful results are obtained in comparing the percentage of sulphurets in the various vein systems. The only rule that might be adduced here is that the veins of the Idaho system in Grass Valley are poor in sulphurets, but against this stands the fact that the parallel Orleans vein near Nevada City is in places rather rich in them.

Character.—On nearly all veins pyrite predominates; the exceptions are certain mines in Willow Valley and the vicinity of Canada Hill, where arsenopyrite or zincblende (Beckman vein) prevails. In the Merrimac and Union veins galena is said to prevail. In nearly all veins there is, besides pyrite, galena, zincblende, and chalcopyrite. The veins with arsenopyrite are confined to certain localities, as indicated in the pages on mineralogy, but not to any certain kind of vein or country rock. In fact, any attempts to correlate the character of the sulphurets with the country rock appears a failure. Certain veins in granodiorite contain no arsenopyrite; other veins in the same rock show this mineral in large quantity.

Contents of gold and silver.—The sulphurets in the quartz always contain gold and silver. Those from the altered country rock also contain some, but are generally much poorer. The concentrated sulphurets, which are not quite pure, but contain a certain quantity of quartz, varying from 5 to 15 per cent, range in value from $40 per ton to several hundred dollars, chiefly in gold.

In any given mine the tenor of the sulphurets generally increases with the richness of the ore. It is found, however, that in many of the Grass Valley mines, which carry rich ore with much free gold, the concentrates are relatively poor. In the Providence and Champion veins, the ore of which is of lower grade, the sulphurets run high in gold, probably averaging not less than 5 ounces per ton. The sulphurets of the great Eureka-Idaho ore shoot are uniformly rich, ranging from 5 ounces of gold per ton upward.

The relative quantity of silver varies also, but only in few mines exceeds that of gold by weight. In most of the sulphurets of the Banner Hill district there is a considerable quantity of silver, probably reaching its maximum in the Banner mines, where the quantity of silver greatly exceeds that of gold and sometimes almost equals it in value. The Federal Loan sulphurets, on the other hand, carry only about 2½ ounces of silver per ton.

In the Nevada City district the greatest percentage of silver is found in the Mountaineer, Merrifield, and Ural veins; at the Champion and Providence mines the sulphurets contain from 10 to 16 ounces of silver per ton, or more than double the amount of the gold. But at the Nevada City, on the same vein, the percentage of silver sinks, and equals or is less than that of the gold.

In the Grass Valley district there is generally only a small quantity of silver in the concentrates. A ratio of almost one-half silver to one part of gold by weight is found in the Empire, North Star, and Slate Ledge; still smaller quantities are reported from the Orleans, Osborne Hill, and Maryland, where it sinks to one-third or less that of gold. The concentrates of the Omaha and W. Y. O. D. carry about twice as much silver as gold.

There is not much definite information as to the contents of the separate minerals of the concentrates, but, as stated above, gold may be seen occasionally included in almost any one of them. In some mines the galena appears to be very rich in gold.

In order to ascertain the relative preponderance of metals, several analyses were made by Dr. Hillebrand of representative concentrates. Two analyses by F. Claudet, quoted by J. A. Phillips in his Mining and Metallurgy of Gold and Silver, are here given under I and II.

Analyses of concentrated sulphurets.

	I.	II.	III.	IV.	V.	VI.
Silica	10.97	14.23				
Titanic acid				.590		
Sulphur	46.70	43.72				
Arsenic	.31	1.36	.155	.041	8.950	.006
Tellurium				.026		.008

Analyses of concentrated sulphurets—Continued.

	I.	II.	III.	IV.	V.	VI.
Gold	.04	.03	Not det.	.013	.004	Not det.
Silver	.04	.01	Not det.	.033	.005	.044
Iron	41.65	39.25	....	....	....	....
Nickel	....	....	.025	.850	.013	.024
Cobalt	....	.15	(?)	.110		
Chromic oxide	....	....	....	1.620	....	....
Copper	Trace.	0.22	.030	.820	.069	.564
Lead	Trace.	Trace.	.240	1.008	.395	2.730
Zinc	....	....	.065	Trace.	.370	1.190
Cadmium	....	....	....	....	Trace?	.053
Bismuth	....	....	....	....	Trace?	.008
Tin	....	....	....	....	Trace?	Trace?
	99.71	98.97				

I. Grass Valley. Analyst, F. Claudet.
II. North Star. Analyst, F. Claudet.
III. North Star. Analyst, W. F. Hillebrand.
IV. Maryland. Analyst, W. F. Hillebrand.
V. Federal Loan. Analyst, W. F. Hillebrand.
VI. Providence. Analyst, W. F. Hillebrand.

Attention is called to the unexpectedly large percentage of tellurium in the Maryland mine. Tellurium was also found in the sulphurets from the Nevada City mine, while those from the Empire and Omaha mines gave negative results. The presence of bismuth, cadmium, and possibly tin is of interest. Chromic oxide is found only in the Maryland mine, occurring on the contact of serpentine and diabase. At the time of this examination there was considerable altered country rock milled containing quartz stringers, and it is not impossible that the Cr_2O_3 may have been derived from that.

THE VALUE OF THE ORES.

High-grade ores are found on the narrow veins of the Banner Hill district, even reaching $50 and $100 per ton, but a good average of the mines working on a large scale would probably be $15 to $20 per ton. In the Nevada City district the average would probably also be $15 per ton, though there are great variations, many of the minor veins containing small but very rich pay shoots. In Grass Valley the average tenor is decidedly higher. Fair statistics are available, from which it is clear that it is in this vicinity $20 per ton. No law can be deduced as to the tenor of the ore in different country rocks. Rich ore shoots appear to occur in all formations.

The value of the free gold obtainable by simple amalgamation is generally much higher than that of the gold in the sulphurets. Rarely, as in the North Banner, does the gold in the sulphurets equal the quantity of free gold.

The value of the gold always greatly exceeds that of the silver; counted by weight, there are only a few mines in which the silver approaches or equals the weight of the gold produced. Among these are many of the Banner Hill and Willow Valley mines. The ratio between gold and silver by weight, though variable in the same mine, is, for instance, 1:1 in the Lecompton, 4:3 in the North Banner, 7:4 or 5 in the Mountaineer. In the Providence and Champion mines it appears to vary from 5:1 to 7:10, the latter being the highest figure for silver recorded.

These figures are derived from the tables of production of the mines in the Mint Reports. It is believed that the assay values would show a somewhat higher percentage of silver, for the reason that in treating argentiferous gold ores a relatively larger quantity of silver is lost in the tailings.

SUPERFICIAL ALTERATION.

The upper part of the vein near the surface is generally decomposed and forms a reddish, crumbling or soft mass of limonite and quartz. The process consists, as is well known, in an oxidation of the sulphides, with accompanying liberation of the gold and a general loosening of the texture. This decomposition extends a variable distance from the surface, very seldom, however, more than 200 feet on the incline of a vein dipping 45° or below a vertical depth of 150 feet. On the other hand, it is common enough, especially in veins with little sulphurets, to find fresh ore almost at the surface. The process is, on the whole, of slight extent and importance compared with other mining districts. In consequence of the liberation of the gold from the sulphurets, the surface ores are easily reduced, and in consequence of the removal of other substances than the gold, they are also generally richer than the fresh ore below. In this process the silver is also partly removed. The decomposed croppings of the Grass Valley veins often contained from $80 to $300 per ton, while the average tenor in depth is from $20 to $30. At present very little of this surface ore remains.

THE STRUCTURE OF THE ORE.

Differing structures.—Four distinct kinds of structure occur in the ores:

1. Massive structure. Massive quartz with sulphurets in wholly irregular distribution. No law can, as a rule, be discovered in the order of deposition of the different sulphurets. This structure is very common.

2. Banded structure by deposition. In this somewhat less common form of structure distinct bands or streaks of sulphurets lie in the generally massive quartz parallel to the walls of the vein. In the Providence shoot of the Ural vein this structure was beautifully shown, and is mentioned from many other places in the detailed descriptions. No definite rule could be made out as to the distribution of the different

sulphides, all frequently occurring mixed in one streak. It has, however, been noted that the chalcopyrite is, often at least, later than the galena and pyrite. The banded structure is illustrated by Pl. VII, fig. *a*, showing Omaha ore with banded pyrite on the left. In smaller veins both of these structures are frequently found with druses and transitions to comb structure. (Pl. VIII, fig. *a*.) Symmetrical deposition of bands on both walls is not often seen, probably on account of the flat dip of the veins. The sulphurets occurring in banded form by deposition are very often shattered by subsequent slight movement. Such a shattering may, to some extent, be seen in the specimen from the Omaha mine (Pl. VII, fig. *a*), but in far more characteristic form in the specimen shown in Pl. VIII, fig. *b*, illustrating ore from the twentieth level of the Empire mine. In this specimen minute specks of gold may be seen plentifully sprinkled in the pyrite and galena.

3. Banded structure by subsequent movement on the vein, or *ribbon structure* proper. This form is extremely common, but has rarely been recognized as due to a sheeting of the vein after its deposition. The explanation generally given for it is that it is due to deposition or to reopening of the vein. The structure is characterized by the branching of the cracks in detail and by the drawn-out streaks of sulphurets noted along the fissures. Gold is frequently found in plates and coatings along these sheets, evidently deposited as a secondary concentration. The microscopical structure gives conclusive evidence as to the crushing of the quartz.

Pls. IX and X show the ribbon structure of the Merrifield vein, Providence mine, stopes between thirteenth and fifteenth levels. The vein is 20 inches wide; 12 inches on the foot wall show massive white quartz with some sulphurets, and with small cavities in which crystal points protrude. The next 5 inches are partly shattered, and a strong sheeting is developed in the last 3 inches next to the hanging wall. Again, the branching character of the cracks and the drawn-out streaks of pyrite and galena are characteristic; no gold is visible with the magnifying glass. Only the upper half of the vein is represented on the photograph.

Finally, the ribbon structure, in contrast to the banded structure, is illustrated in Pl. VII, fig. *a*, from the Omaha mine, fourteenth level. Free gold is seen with the magnifying glass both in the banded pyrite and galena and in the pyrite along the fissures to the right.

4. Banded structure by reopening. A banded structure is sometimes met with which is apparently due to the reopening of the filled vein and the deposition of a new layer. Structures probably due to this have been noted from several places, but they are not always easy of identification as such, for an interruption in the vein-filling process might have produced a very similar result. A good example of this structure is shown in a vein 1½ inches wide from the Osborne Hill mine. The vein is divided in two by a surface covered with small crystals of arsenopyrite, and each part shows independent comb structure.

Microscopic features.—The normal vein quartz has a very characteristic granular, hypidiomorphic structure, which in its essential features remains the same, though the dimensions of the grains may vary greatly. The grains border partly with irregular lines, partly with crystallographic outlines, and the larger grains are penetrated by smaller, more or less perfectly developed quartz crystals. This is illustrated on Pl. IV, figs. *a* and *b*. Miarolitic cavities, in which the points of crystals project, are common, and are filled with calcite or opal. The galena, chalcopyrite, and blende never show crystal form, while cubes of pyrite are frequently seen, and arsenopyrite nearly always appears, with crystallographic outlines.

Other minerals than quartz are rarely present. Calcite occasionally appears, and sericite also, the latter confined to the vicinity of fragments of country rock and never embedded in the massive quartz. Shreds of chlorite occasionally appear in the quartz (Maryland mine). Barite and fluorite do not occur. Feldspars, zoisite, and epidote have not been detected in the vein quartz.

Fluid inclusions are extremely abundant; they are usually small, of irregular form, sometimes have rapidly moving bubbles, and are, as a rule, arranged in different planes in adjoining grains; a dependence on crystallographic planes is sometimes recognized. In other cases the inclusions are continuous across adjacent grains and show a peculiar radiating arrangement dependent on the sulphides in the quartz; long-drawn form or arrangement parallel with the walls of the veins appears only exceptionally. The bubbles tested did not disappear on heating to $+30^\circ$ C., and it is not probable that they contain carbonic dioxide.

No recognizable relation exists between the fluid inclusions and the richness of the quartz.[1]

During the earlier investigations of Davy, Sorby, Brewster, and Vogelsang[2] a great many specimens of vein quartz, with large fluid inclusions, from Schemnitz, Hungary, Guanaxuato, Mexico, and other localities, were tested, and the results showed that the contents were chiefly solutions of chlorides and sulphates in water.

A large quantity of clean quartz with but little pyrite from the Merrifield vein, Providence mine, fifteenth level, was examined for soluble salts by Mr. George Steiger. Five hundred grams of the powdered rock was treated with cold water for two days; then heated three hours on the water bath and filtered. This gave a milky filtrate which amounted to about 1,000 c. c. The filtrate was evaporated to 50 c. c. and filtered again. This filtrate was perfectly clear, and its analysis is marked B. The residue on the filter was examined separately, its analysis being marked A. This residue contained some carbonates which had evidently been in solution.

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[1] Cf. W. M. Courtis, Trans. Am. Inst. Min. Eng., Vol. XVIII, 1889, p. 639.

[2] Rosenbusch, Physiographie der Mineralien.

[Grams per ton of quartz.]

	A.	B.
SiO_2	3	28
Al_2O_3, Fe_2O_3	2	2
CaO	13	44
MgO	....	1
$(KNa)_2O$	....	29
SO_3	....	78
Cl	....	5
	18	187

The result shows the presence of sulphates of calcium and alkaline sulphates, together with very little chloride. The sulphuric acid could not have been derived from the pyrite, for there is scarcely any iron present. In all probability the soluble salts were contained in the fluid inclusions. Some silica, probably amorphous, has also been dissolved, as well as a little carbonate.

The occurrence of carbonic acid has been shown by Dr. Hensoldt in a specimen of quartz from the Tiger mine, Calaveras County.[1]

It is extremely common to find the vein quartz broken and crushed along certain lines, and the appearance of this crushed quartz under the microscope is identical with the effects of crushing, so often described, in massive granular rocks. An excellent example of this structure is shown on Pl. VI, fig. *a*. The crossed nicols bring out the slight difference in the optic orientation of the crushed parts of each grain. Actual faulting has taken place, and along the fault lines a crushed aggregate of new, ragged, and irregular quartz grains is formed. If this process is carried somewhat farther a sheeting of the vein will result, and along the planes broad streaks of secondary quartz aggregates will be formed. New slight fissures are sometimes formed, and by a process of secondary concentration gold and sulphides may be deposited along these planes. To this the frequent richness of the ribbon quartz is no doubt due. The masses of sulphides in the way of the fractures are broken and pressed out in long streaks. Pl. VI, fig. *b*, shows the structure of the quartz from the large specimen of ribbon quartz illustrated by Pl. IX. The section is made from the quartz next to the wall, and shows well the contrast between the fresher quartz and sulphurets preserved on the left and the finer aggregate structure of the quartz and pressed form of the pyrite on the right. The partings in the ribbon quartz may often show a parallel striation. Under the microscope the ribbon structure by sheeting is distinguished from that by reopening or deposition by the fact that in the latter there is no indication of pressure in the quartz, or at least only on one side of the dividing plane, while the quartz on the other side is deposited as a mold on the parting plane without showing any dynamic disturbance.

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[1] Paper by W. M. Courtis quoted above.

PLATE IV.

THIN SECTIONS SHOWING STRUCTURE OF ORE.

FIG. *a*. Normal vein quartz structure; Federal Loan mine; 39 N. C.
Magnified 17 diameters.
Crossed nicols.
Only quartz.

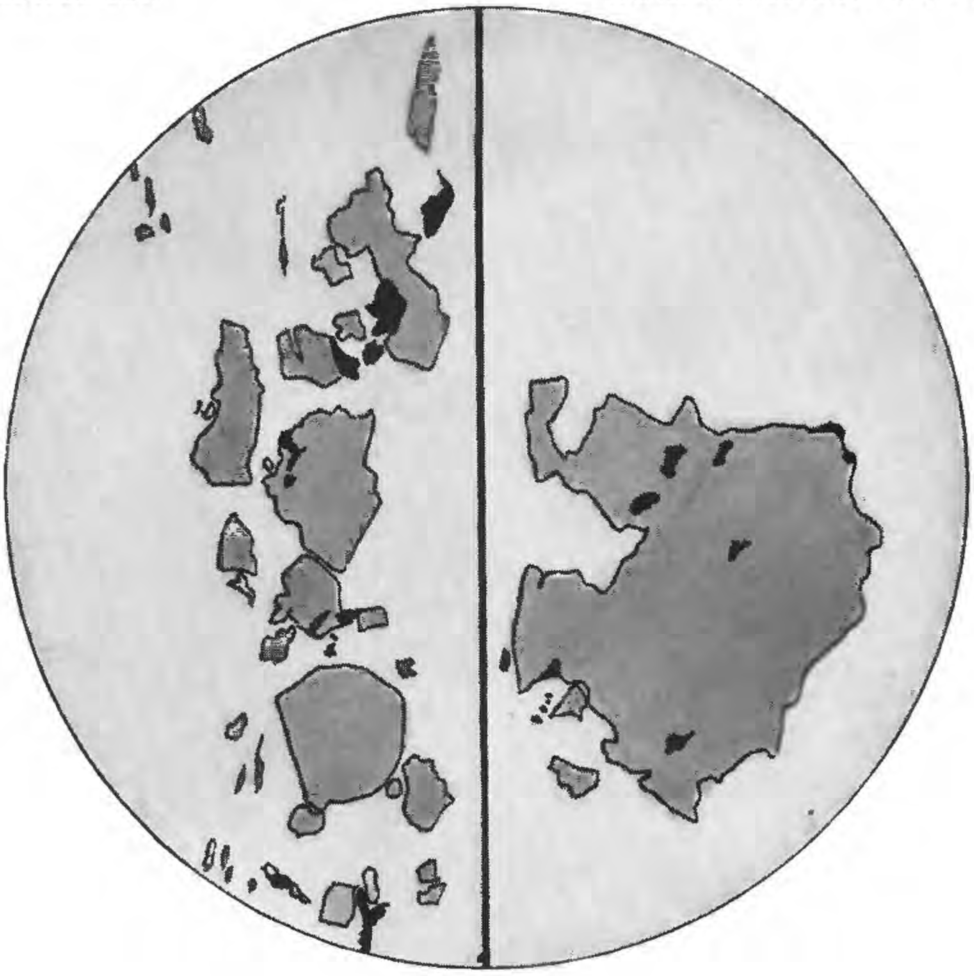
FIG. *b*. Normal vein quartz structure; Osborne Hill mine; 82 G. V.
Magnified 52 diameters.
Black areas, arsenopyrite.
Shaded areas, quartz.

PLATE V.

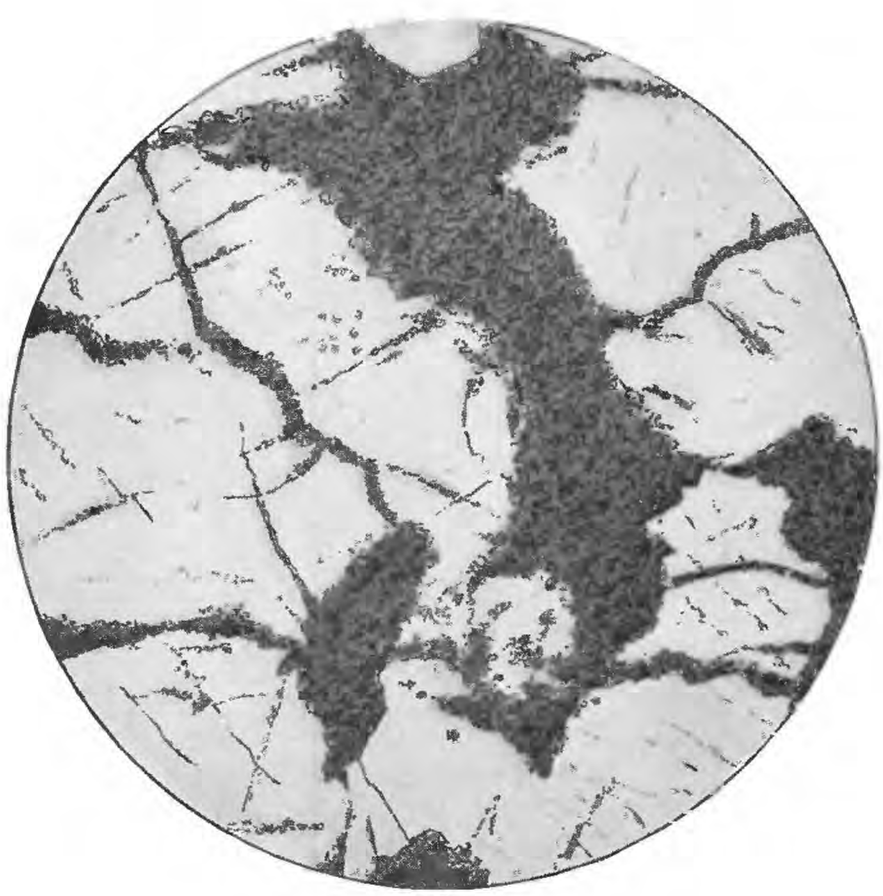
THIN SECTIONS SHOWING STRUCTURE OF ORE.

FIG. *a*. Gold in pyrite and quartz; Omaha mine, fourteenth level; 144 G. V.
Magnified 17 diameters.
White areas, quartz.
Shaded areas, pyrite.
Black areas, gold.

FIG. *b*. Metasomatic replacement of quartz in granodiorite by calcite and sericite aggregates; new shaft, Providence mine; 111 N. C.
Magnified 52 diameters.
White areas, quartz.
Shaded areas, calcite and sericite.

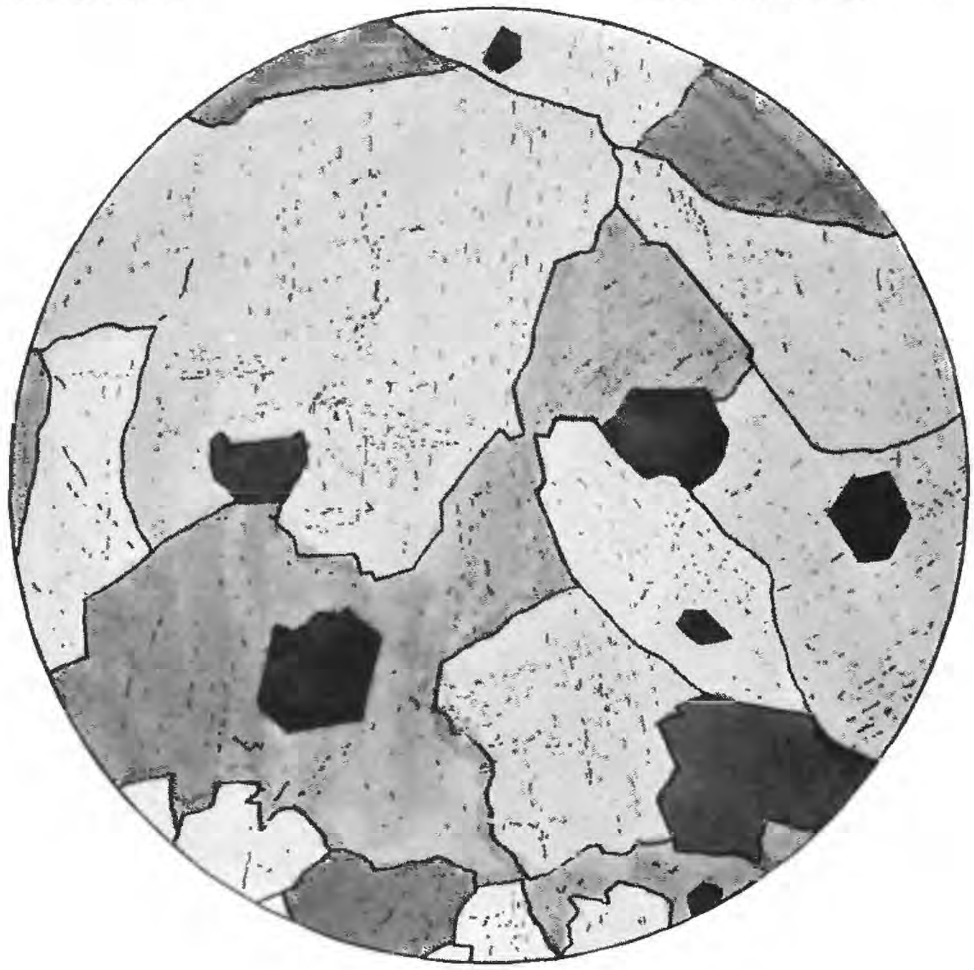


a

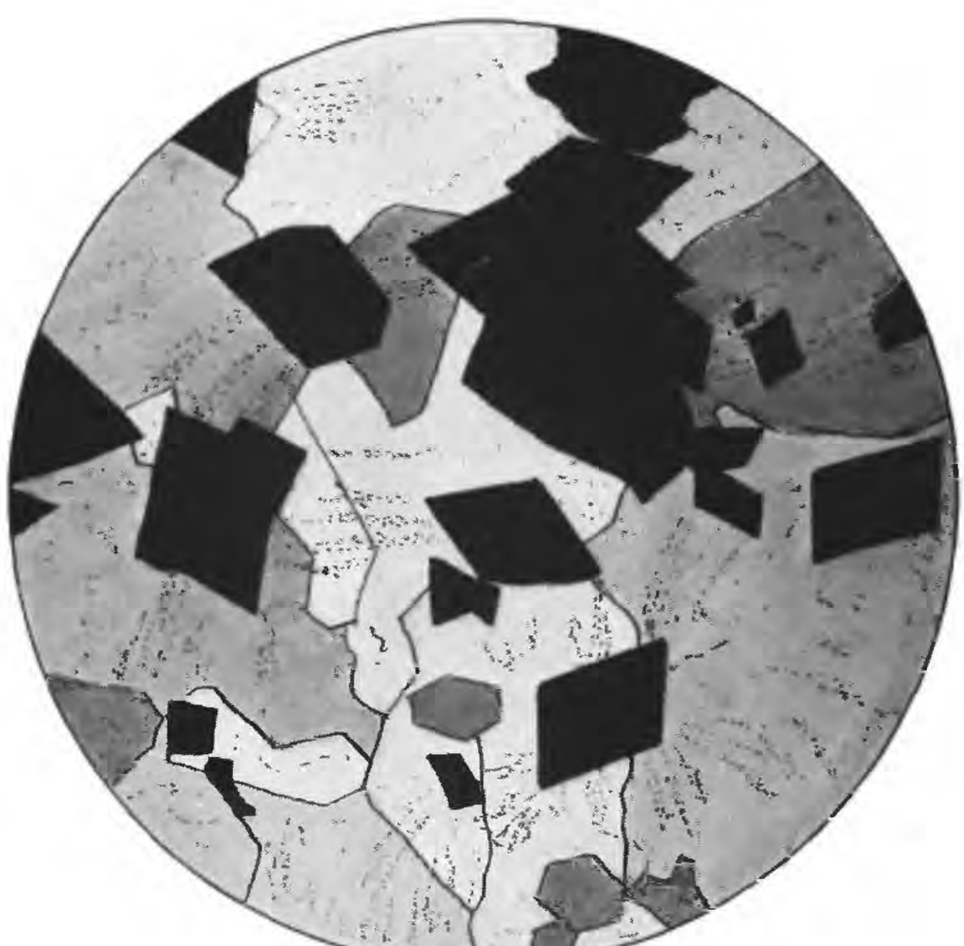


b

THIN SECTIONS, SHOWING STRUCTURE OF ORE.



a



b

THIN SECTIONS, SHOWING STRUCTURE OF ORE.

PLATE VI.

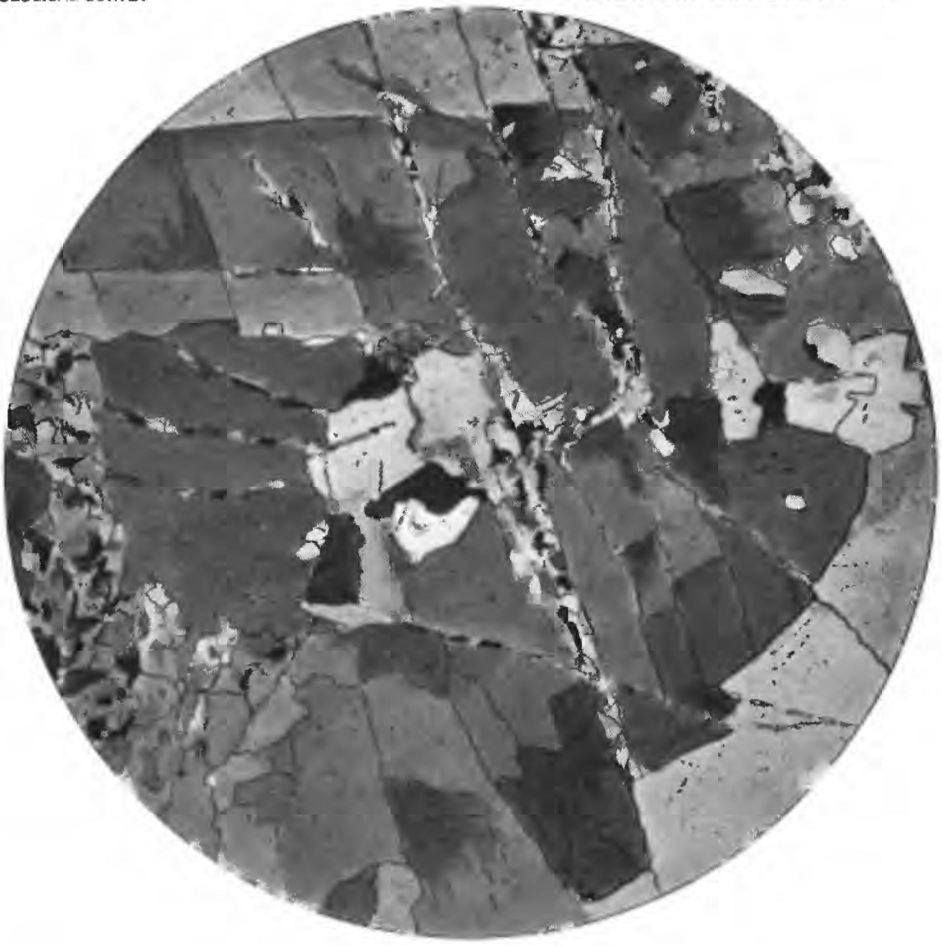
THIN SECTIONS SHOWING STRUCTURE OF ORE.

FIG. *a*. Crushed vein quartz and incipient ribbon-structure; Nevada City mine; 134 N. C.

Magnified 15 diameters.
Crossed nicols.
Only quartz.

FIG. *b*. Ribbon-structure, showing crushed quartz and pressed pyrite. Original aggregates of quartz and pyrite to the left. From specimen shown in Pls. IX and X.

Magnified 17 diameters.
Crossed nicols.
Black areas, pyrite.
All other areas, quartz.



a

b

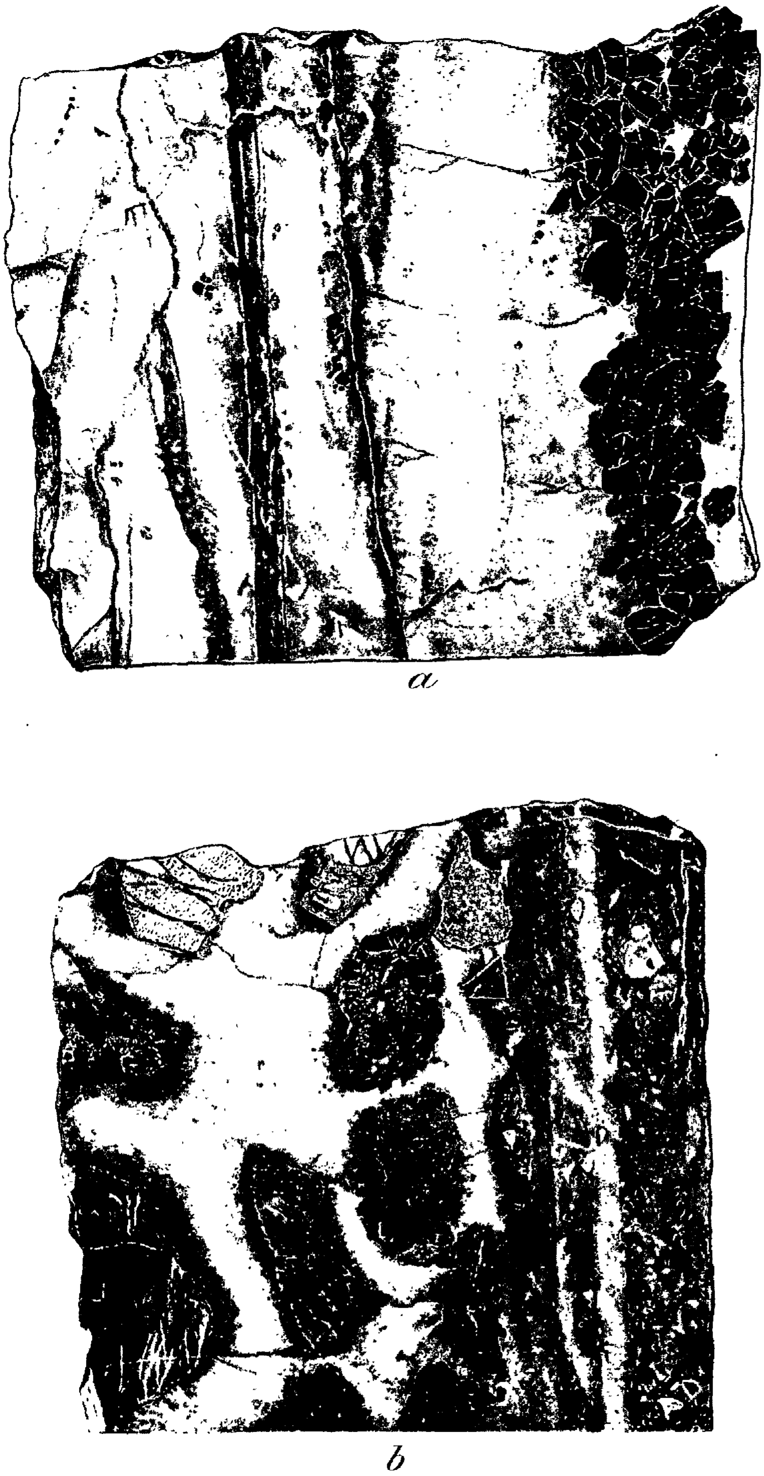
THIN SECTIONS, SHOWING STRUCTURE OF ORE.

PLATE VII.

SPECIMENS SHOWING STRUCTURE OF ORE.

FIG. *a*. Vein quartz; Omaha mine, fourteenth level; 144 G. V. On the right, banded structure by deposition; pyrite somewhat crushed. On the left, ribbon-structure by sheeting of vein after deposition.
Natural size.

FIG. *b*. Vein quartz; Federal Loan mine; 40 N. C. Showing included fragments of black argillite, altered to yellowish-gray calcite-sericite rock, with arsenopyrite, and surrounded by pyrite.
Natural size.



SPECIMENS SHOWING STRUCTURE OF ORE. NAT. SIZE.

PLATE VIII.

SPECIMENS SHOWING STRUCTURE OF ORE.

FIG. *a.* Thin section of 2-inch quartz seam in diorite; California mine, Dead Mans Flat; 143 G. V. Quartz shows comb-structure. The wall rock a basic diorite with pyrrhotite, altering next to vein to calcite, sericite, and pyrite.
Natural size.

FIG. *b.* Vein quartz; Empire mine, twentieth level; 155 G. V. Showing crushing of pyrite and galena, and recementing by later quartz seams.
Natural size.

FIG. *c.* Vein quartz; Banner mine. Showing shattering of black argillite by quartz seams; pyrite developing in the argillite, but not in the quartz; further, brownish (weathered) carbonates deposited next to the argillite in the seams. Beginning of metasomatic alteration apparent by bleaching of the black argillite.
Natural size.

PLATE IX.

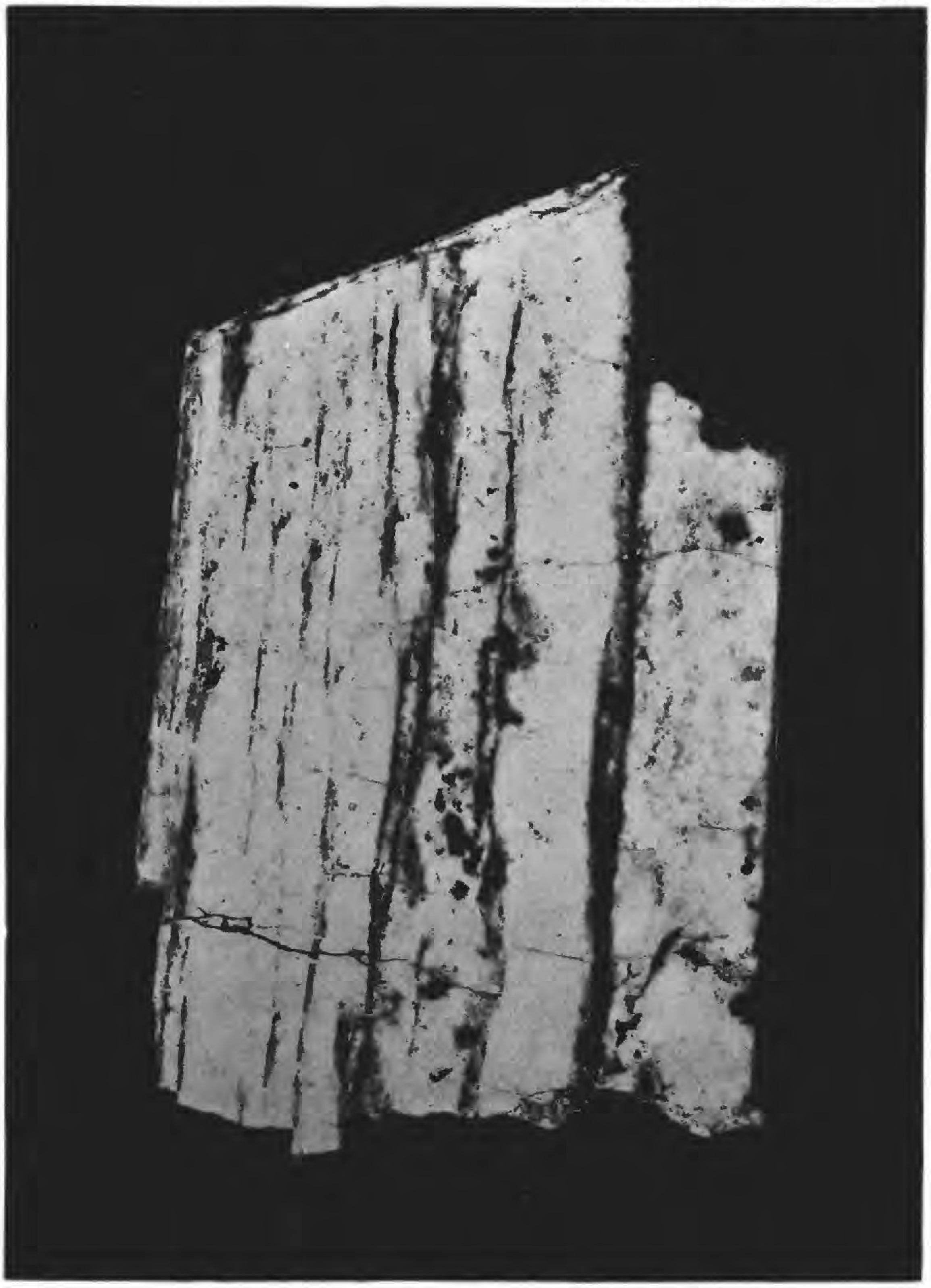
VEIN QUARTZ, MERRIFIELD VEIN.

Vein quartz; Merrifield vein, Providence mine, fifteenth level, south. Vein 2 feet wide; only one-half of it, adjoining hanging wall, is represented. Lower half massive quartz; upper half showing typical ribbon-structure by sheeting subsequent to deposition. Showing branching fissures and pressed pyrite.

Two-thirds of natural size.

SPECIMENS SHOWING STRUCTURE OF ORE. NAT. SIZE.

SPECIMEN FROM MERRIFIELD VEIN, SHOWING STRUCTURE OF ORE.



SPECIMEN FROM MERRIFIELD VEIN, SHOWING STRUCTURE OF ORE.
Natural size.

PLATE X.

VEIN QUARTZ, MERRIFIELD VEIN.

Specimen from Merrifield vein, fifteenth level, south; showing typical ribbon-structure with branching fissures and pressed pyrites.

CHAPTER X.

CHANGES IN THE ROCKS DUE TO FISSURE AND VEIN FORMATION.

GENERAL FEATURES.

Along the veins the rocks show notable mechanical and chemical changes. The first is shown by lines of fracture and by breccias, cemented by quartz. It is also, but more rarely, shown by wide-reaching mechanical deformation of the rock, producing schistose and slaty structure. The character of the fissures as integral parts of extensive sheeting and jointing implies less of a long-continued and intense movement on the shearing planes, and more of a sudden break or crush, with the formation of a single fissure or of breccias and branching veinlets. The chemical change is of uniform character, and is always present, but may be more or less emphasized; its universal occurrence and the mineralogical character of the process point unmistakably to a chemical reaction and interchange of substance between the rock and some fluid once filling the fissures. In other words, it is a process of substitution or metasomatic replacement.

MECHANICAL ALTERATION.

The breaking and brecciating of the rocks along the fissures have not, as a rule, produced an extensive mechanical alteration, though in coarse-grained rocks the constituents are often, under the microscope, seen to be somewhat crushed, and the quartz grains often acquire undulous extinction. More rarely appears a schistosity of the rock next to the vein, produced by the shearing force exercised in breaking the fissure, and also by the grinding of the walls against each other after the break.

It is only along the Merrifield and Ural veins, on which, as shown in the detailed descriptions, extensive faulting has taken place, that this schistose structure is developed on a large scale. This is especially well seen in the Champion, Providence, and Nevada City mines. The zone in which the schistosity is developed is from a few feet up to 20 feet wide, and in it one or several quartz veins may be contained, as explained. The granodiorite is converted to a greenish-gray rock, breaking in flat irregular fragments, bounded by smooth greenish faces with greasy feel. The planes of schistosity are curved, and the structure is produced irregularly, less altered masses alternating with thoroughly schistose streaks. The chemical alteration of these rocks is intense, and will be discussed later. The mechanical deformation is equally pronounced. The quartz grains are completely shattered; the whole coarse aggregate of the granodiorite is crushed to a greenish, fine-grained, allotriomorphic aggregate, often with a somewhat splintery fracture, drawn out in long streaks and stringers. The carbonaceous schist of the Ural foot wall is equally crushed, though the effect on the individual grains is here not visible, owing to the original fineness of grain. The resulting mass is a black, soft rock with irregular and curved black and shining planes of schistosity, much more irregular, in fact, than the original planes of schistosity of the rock.

CHEMICAL ALTERATION.

GENERAL FEATURES.

The chemical alteration which the rock next to the quartz has undergone is developed with very different intensity., In some mines, indeed, like the Mountaineer and Omaha, sometimes also in the Empire and North Star, comparatively fresh rock lies close up to the vein, while in others the zone of alteration may be several feet wide. The most extensively altered rock is usually the brecciated mass lying between two closely approaching fractures or walls. The resulting rocks, often entirely different in appearance from the fresh rock, usually have a yellowish-gray to gray or white appearance, and frequently a greasy feel. It is easy to find all kinds of transitions, from the incipient to the most advanced alteration. All rocks are subject to this alteration, even the siliceous argillite from the Federal Loan; in carbonaceous fissile argillites, however, such as in the Merrimac mine, the alteration is very slow and chiefly confined to the introduction of pyrite. All minerals are subject to it, even the quartz of the granodiorites.

MINERALOGICAL CHARACTER OF ALTERATION.

The changes in the rocks are chiefly due to the formation of three classes of minerals: (1) *Carbonates*, chiefly calcite, pure, or more frequently with a small admixture of the carbonates of iron and magnesium, the former producing a brownish color in weathered fragments. Near veins in serpentine the magnesium carbonate prevails. (2) *Potassium micas*, usually in fine-felted aggregates of wavy fibers, with often silky luster; the name sericite has been used for these micaceous aggregates, according to precedent, although it is probable that the composition varies little if any from that of normal muscovite. It is hardly ever possible to obtain the mineral in a sufficiently pure state for analysis. Other potassium micas occurring connected with altered wall rocks are the so-called mariposite (cf. p. 115), which is colored green by chromium and is probably identical with fuchsite. A vanadium mica, roscoelite, also occurs on veins in Eldorado County. (3) *Sulphides*; pyrite is extremely abundant in sharp, cubical crystals, and in some mines arsenopyrite also appears in idiomorphic forms. Calcite or quartz rims often surround the cubes of pyrite.[1] No other sulphides have been observed. Pyrrhotite, which is extremely common as a result of metamorphic processes in certain rocks of the district, is not found in the altered wall rock. Abundant examples show that it is transformed into pyrite when within the influence of the fluids circulating on the fissures.

Besides these principal groups of minerals others may occur. Small quantities of chlorite have been observed, but the process is on the whole not favorable to the development of this mineral; titanite (leucoxene) is frequently present, due to an alteration from ilmenite or titaniferous magnetite; chromite has been observed; magnetite is absent, and seems to have been converted into ferrous carbonate or perhaps also into pyrite.

This process is one of metasomatic interchange—that is, "an interchange of substance without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced, or even of its original volume."[2]

Metasomatic interchange or replacement, in a restricted sense, necessitates chemical action between the mineral attacked and the solvent; of such character are, nearly exclusively, the processes here described. In a wider sense, it also includes processes by which the original mineral is dissolved as a whole and a new substance deposited in its stead without chemical action between the two substances, as, for instance, in the case of quartz replacing calcite.

Replacement by silica is not among the processes here recognized. It should be borne in mind that a rock shattered and filled with quartz seams is not an evidence of metasomatic replacement by quartz, nor is such a rock a quartz vein in process of formation. In a mineral water containing carbon dioxide, sulphureted hydrogen, carbonates, and silica, the former three compounds will vigorously attack, by chemical processes, the minerals of any ordinary rock, and form new compounds, while the silica is inert and plays a passive rôle. It has not been noted that the silica in the mineral waters forming the vein has replaced any of the rock minerals. Most of the silica set free by the process of carbonatization has probably been removed and deposited in the fissures, while some of it—especially where thermal waters permeate whole rock masses and no free ducts exist—may be deposited in the altered rock as secondary aggregates. If a silicification of the wall rocks is found at any place in the California gold-quartz veins, it will probably be in easily soluble rocks, such as limestone.

It is necessary to separate strictly the quartz filling in the veins deposited in open spaces from the metasomatic country rock. The

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[1] The ease with which large idiomorphic crystals of pyrite may develop in certain rocks, such as the chloritic diabase of the Idaho and the Kentucky mines, is very remarkable as showing the intensity of the metasomatic process.

[2] Emmons, Mon. U. S. Geol. Survey, Vol. XII, p. 565.

latter, however altered, bears evidence of its metasomatic character, while the former, in its structure, clearly indicates a crystallization in open space.

In the ordinary course of the metasomatic process, as here shown, augite, hornblende, uralite, feldspar, and epidote are first vigorously attacked. Proceeding along cracks in the minerals, a finely felted calcite and sericite aggregate invades the grains until the replacement is complete. The hornblende is sometimes converted directly into coarse foils of muscovite, and in the feldspar grains there is often, also, a distinct tendency of the sericite fibers to parallel arrangement, finally resulting in the forming of large foils. An interlacing structure of mica foils with the interstices filled with calcite is sometimes met with (Federal Loan). The quartz is also attacked, but with more difficulty than the other minerals; from many localities there is unequivocal evidence of a process of replacement gradually eating away the quartz. In fig. *b* of Pl. V the resulting aggregate is chiefly composed of calcite with a little sericite. In other slides the product is chiefly sericite. The relative preponderance of the carbonates and the mica is subject to variation in the same mine. As the examples below indicate, they usually occur together, but occasionally (analysis from the Idaho) the carbonates may entirely prevail, or (analysis from the Osborne Hill) the rock may be almost entirely composed of sericite. The quantity of pyrite is usually large, and it appears as if the pyrite were derived mostly, not from the magnetite, but from the ferrous silicates.

In addition to the metasomatic alteration, the rock is very commonly traversed by small fissures, which generally are filled with carbonates or a mixture of carbonates and quartz, more rarely with quartz alone. This characteristic is often very prominent, and it seems at first glance strange to see the quartz vein adjoined by a rock traversed in all directions by veinlets of carbonates.

SUBSTANCES LOST OR INTRODUCED.

The chief and marked characteristics of the altered wall rock are the introduction of carbon dioxide, sulphur, and potassium; the latter is especially emphasized, because the prevailing rocks of the districts are decidedly richer in sodium than potassium, and the conclusion is unavoidable that not only has the sodium been leached out but potassium actually introduced in the rock. Analysis I of the altered wall rocks is especially instructive compared with the analyses of fresh granodiorites.

The percentage of silica is lowered by at least 10 per cent; the aluminum appears fairly constant, as does the iron, though part of it is converted into sulphides. The calcium in some cases remains constant, while it is considerably increased in most rocks; the magnesium is not much changed. Sodium has been extensively removed. Titanic acid remains constant, as does the phosphoric acid of the apatite.

In some analyses the presence of barium in not greatly differing quantities from that of the fresh rock is of interest. Water, above 110° C, is present in pretty constant quantity, ranging from 1 to 3 per cent; extensive hydration has certainly not taken place, and in the case of altered serpentines there is a distinct dehydration.

Analyses of altered wall rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	56.25	60.26	59.76	34.91	36.19	45.74	58.43	71.97
TiO_2	.25	.42	.46	1.65	.16	.36	None.	.88
Al_2O_3	17.65	15.73	14.45	15.55	4.93	5.29	17.40	15.75
Fe_2O_3	.76	1.25	1.04	.17	.21	.13	.77	.77
FeO	*a*2.64	2.68	3.52	*a*4.96	5.36	2.06	*a*2.19	*a*.45
FeS_2	2.87	.08	.24	4.20	.22	.49	1.59	.56
MnO	None.	.04	.09	None.	.12	.26	None.	None.
NiO	....	....	....	....	*b*.10	....	....	....
CaO	4.46	5.44	6.09	11.10	4.60	23.85	5.25	.80
SrO	....	Trace.	Trace?	....	Trace.	None.	....	....
BaO	.03	.07	.05	None.	Trace.	Trace.	None.	Trace.
MgO	1.69	1.82	2.26	4.58	22.94	*c*.94	1.50	.80
K_2O	6.01	3.71	3.73	4.28	.06	1.29	4.03	4.88
Na_2O	.30	1.92	1.12	.19	.16	.11	1.76	.33
Li_2O	....	Trace.	Trace.	....	Trace.	Trace.	....	....
H_2O below 110° C	.30	.33	.26	.30	.18	.22	.30	.30
H_2O above 110° C	2.36	2.54	2.58	1.86	2.87	1.07	2.61	2.16
P_2O_5	.21	.12	.16	.82	.05	.07	.13	.15
CO_2	4.82	3.99	4.47	15.57	21.82	18.91	4.04	.38
SO_3	None.	....	....	None.	....	....	None.	Trace.
	100.60	100.40	100.28	100.14	99.97	100.79	100.00	100.18

I. Bellefountain tunnel (42 N. C.), derived from granodiorite. Analyst, George Steiger.
II. Providence mine, front vein (208 N. C.), derived from granodiorite. Analyst, W. F. Hillebrand.
III. Providence mine, back vein (212 N. C.), derived from granodiorite and schist. Analyst, W. F. Hillebrand.
IV. Federal Loan mine (38 N. C.). Analyst, George Steiger.
V. Idaho, 16th level (148 G. V.), derived from serpentine. Analyst, W. F. Hillebrand.
VI. North Star mine (104 G. V.), derived from uralite diabase. Analyst, W. F. Hillebrand.
VII. Empire mine (151 G. V.), derived from granodiorite. Analyst, George Steiger.
VIII. Osborne Hill mine (83 G. V.), derived from fine-grained sandstone. Analyst, George Steiger.

[a] These determinations of FeO were unsatisfactory on account of FeS_2.
[b] Nickel not looked for elsewhere, but certainly not present in more than traces.
[c] Approximate.

For comparison the following analyses of fresh rocks are appended:

Analyses of unaltered rocks.

	I.	II.	III.
SiO_2	66.65	51.01	73.63
TiO_2	.38	.98	.52
Al_2O_3	16.15	11.89	10.54
Fe_2O_3	1.52	*a* 1.57	*b* 1.87
FeO	2.36	*a* 6.08	
MnO	.10	Trace.	Trace?
Cr_2O_3	....	.04	....
CaO	4.53	10.36	2.47
CuS	....	Trace.	....
SrO	Trace.	....	Trace.
BaO	.07	None.	.12
MgO	1.74	8.87	1.84
K_2O	2.65	.15	1.89
Na_2O	3.40	4.17	1.81
Li_2O	Trace.	....	Trace.
H_2O below 110° C	.18	.24	.11
H_2O above 110° C	.72	2.09	1.07
P_2O_5	.10	.17	.13
CO	....	....	.62
FeS_2	.02	1.73	....
Fe_7S_8?	....	....	3.16
Carbon of organic matter	....	....	.59
	100.57	99.35	100.37

I. Granodiorite, Shurtleff's barn, Nevada City. Analyst, W. F. Hillebrand.
II. Diabase, 600 feet south-southeast of Maryland shaft (121 G. V.). Analyst, H. N. Stokes.
III. Siliceous argillite somewhat contact-metamorphosed, Federal Loan (38 N. C.). Analyst, W. F. Hillebrand.

a Fe_2O_3 and FeO are approximate only because of presence of sulphides.

b Because of the organic matter and soluble sulphide the FeO could not be estimated. Therefore all iron after deduction of that needed for Fe_7S_8 is counted as FeO. The FeO given in other analyses where there is much pyrite is perhaps only near the truth. Any error in such cases of course affects the Fe_2O_3 in an opposite direction.

On the whole, the analyses show a relatively small amount of leaching of any substance except silica and sodium; large quantities of the latter especially have been removed.

EXAMPLES OF ALTERED GRANODIORITE.

A specimen from the Bellefountain tunnel, Banner Hill tract, is of a yellowish-gray mottled color and granular structure, made evident by quartz grains and darker spots representing remains of hornblende. Sharp, cubical crystals of pyrite abound. Under the microscope the granitic structure is very clear. The hornblende and mica are converted into large muscovite foils. The black iron ores are converted into milky opaque substances. The feldspars are completely changed into a fine-grained sericitic aggregate, often showing approximately parallel arrangement of the fibers, or, also, two systems of fibers at right angles. Smaller masses of calcite lie between the sericite fibers. Sharp cubes of pyrite lie in the aggregate, containing included masses of the micaceous mineral. There is practically no feldspar left, while many of the quartz grains have retained their original form. In other grains the sericite is undoubtedly corroding the quartz grains in exactly the same manner as shown from the specimen 111 N. C. on Pl. V, fig. *b*.

Analysis I in the table shows the composition of this typical rock. Estimating that there is 25 per cent of unaltered quartz in the rock, the constituents may be calculated as follows:

	Per cent.
Calcium carbonate	7 23
Magnesium carbonate	2.70
Iron carbonate	.58
Pyrite	2 87
Apatite	.46
Titanite	.60
Quartz	25 00
Sericite	61.11
	100.55

The composition of the sericite may be calculated as follows:

	Per cent
SiO_2	51.09
Al_2O_3	28.87
Fe_2O_3	1.25
FeO	3.85
MgO	.66
BaO	.05
K_2O	9.83
Na_2O	.50
H_2O	3.90
	100.00

This corresponds fairly well to an acid muscovite, except that the FeO is too high; this may be explained by the uncertainty of its determination in the presence of so much FeS_2.

The crushed and schistose granodiorite from "New Shaft" on the Merrifield vein, Providence mine (111 N. C.), is a grayish-green mottled rock with curved planes of schistosity and greasy feel. It effervesces strongly with hydrochloric acid. The feldspars and hornblende are entirely converted to micaceous aggregates, with irregular patches and veinlets of calcite. Much of the quartz remains, but is nearly everywhere, in the process of conversion to calcite, mixed with a little sericite. The quartz is greatly crushed and drawn out to lenticular aggregates. A portion of this slide is illustrated in Pl. V, fig. *b*; the quartz is somewhat crushed, but is still plainly seen to be composed of only one or two original grains. The small calcite grains forming abundantly along or near the cracks in the fresh quartz are very characteristic, and the whole is unquestionably a process of metasomatic replacement.

In a fissured quartz grain the individual cracks might be filled with calcite, and thus the appearance of metasomatic replacement created. The criterion of the replacement is the inward progression of the new aggregates, resultiug in irregular and ragged masses, and the fact that the separated portions of the quartz no longer fit together.

Specimens from the Merrifield vein in Providence mine, thirteenth level, show the same greenish-gray mottled and schistose rock, sometimes almost serpentinoid in appearance; in places granitic structure is still visible. Small seams of quartz and calcite traverse the rock, and sharply defined cubes of pyrite lie embedded in it. Under the microscope the rock is very similar to the one just described; the quartz is in places drawn out to long strings of aggregates; calcite seams surround the pyrite; the feldspar is largely converted to sericite with calcite. A little chlorite is also present. The analysis of this rock is shown under II, p. 149. It is essentially similiar to I, except that the alteration has scarcely proceeded so far, as is evidenced by the greater percentage of MgO, not needed for carbonates and belonging to the chlorite, and also by the larger remaining percentage of sodium.

The altered granodiorite from the Empire mine, twentieth level, occurring close up to the quartz (151 G. V.), presents the same appearance and effervesces greatly with acid.

The microscopic character is practically identical with the specimen already described, and Analysis VII shows that the composition is also practically identical. Many small veins of quartz cut the sericitic aggregates.

EXAMPLES OF ALTERED DIABASE.

A specimen of the altered porphyritic uralite-diabase from the hanging wall of the North Star vein, twentieth level (10 G. V.), is a grayish-green rock with fine-grained groundmass and small greenish feldspar crystals. Under the microscope the rock is shown to be far more altered than its appearance would indicate; the diabasic structure of feldspar grains, in part interlocking, in part lath-like, is still visible but greatly obscured by an all-pervading aggregate of sericite, calcite, and chlorite. Grains of titanic iron ore or titaniferous magnetite are in process of alteration to a bluish-white substance, probably titanite.

The partly crushed rock between the walls of the vein is greenish-gray, soft and dense, and is traversed by narrow veinlets of carbonate, quartz, and pyrite. The alteration has here gone further and the original structure is scarcely recognizable. The analysis of this rock is given under VI, from which it is apparent that a great quantity of calcite is present. The analysis may be roughly calculated as follows:

	Per cent.
Calcite	42.15
Magnesite	.71
Pyrite	.50
Quartz	35.00
Titanite	.85
Sericite (with chlorite)	20.79
	100.00

The sericite is not pure, as is evidenced by the strong percentage of MgO and FeO. The latter is very high, and it is not certain to which mineral it properly belongs.

The diabase of the hanging wall of the Idaho-Maryland mine is not altered to such an extensive degree as the size of the vein would lead one to suppose. It is a soft, green, chloritic rock, containing only relatively small amounts of carbonates and sericite, but there is much iron pyrites in sharp crystals up to several millimeters in diameter. The microscope reveals a fairly well preserved diabasic granular structure, veiled by films and masses of chlorite; the titanic iron ore is converted to milky opaque aggregates.

EXAMPLE OF ALTERED SERPENTINE.

The serpentine of the foot wall of the Idaho-Maryland vein is, in places, greatly altered. Specimens (147 G. V.) from the sixteenth level near the shaft show near the vein a grayish-green, distinctly schistose rock, soft and with greasy feel. At first glance it has the appearance of a little-altered serpentine. Under the microscope it is, however, shown to consist predominantly of carbonates in coarsely granular aggregates between which lies an intimate mixture of chloritic, serpentinoid, and sericitic fibers. Grains of chromite, translucent with deep-brown color, do not appear to have been altered. At the same locality a large mass of the country rock (148 G.V.) is included in the quartz, and this shows a still farther reaching alteration. It is greenish-gray and distinctly schistose; remaining films and streaks of greenish serpentine or chlorite appear in a predominant gray, finely granular mass. Under the microscope the principal constituent is seen to be magnesite in large grains; there is a little chromite, and many veinlets of quartz. Between the carbonate grains and extending into them lie wavy parallel streaks of a pale-greenish mineral, in part chlorite, in part serpentine. A few grains of pyrite, but almost no sericite, are noted. There are also in intimate connection with the serpentine fine-grained aggregates of quartz. The analysis of this specimen is recorded under V in the table, p. 149. It may be calculated as follows, under the supposition that all of the calcium and the larger portion of the magnesium are present as carbonates, and that there is about 26 per cent free silica present:

	Per cent.
Magnesium carbonate	34.78
Calcium carbonate	8.22
Quartz	26.00
Serpentine, chlorite, and accessories	31.00
	100.00

The residue of serpentine, etc., would then have the following composition:

	Per cent.
SiO_2	34.23
Al_2O_3	16.56
FeO	18.00
MgO	21.57
H_2O	9.64
	100.00

This is evidently a mixture of minerals, probably chiefly chlorite and serpentine. As in the other analyses, the ferrous oxide is in excess, and it is doubtful to which mineral it belongs. The chromium in the rock has not been determined. The free quartz in the analysis results partly from the small veins intersecting the rock, but some of it represents without doubt the silica liberated by the conversion of the magnesian silicates into magnesite.

EXAMPLE OF ALTERED SEDIMENTARY ROCKS.

The massive siliceous argillite from the Federal Loan, of which an analysis is appended on a preceding page, shows under the microscope a very fine grained allotriomorphic aggregate of quartz, feldspar, and brown mica, together with much pyrrhotite and some organic matter. Under the metasomatic influence of the vein solutions this is altered to a yellowish-gray aggregate of sericite, calcite, and residuary quartz; the pyrrhotite is changed to pyrite. This alteration is, in a general way, well shown on Pl. VII, fig. *b*, representing in natural size a piece of vein quartz adjoining the wall in the Federal Loan mine. Next to the wall there will be observed a large number of small angular fragments of thoroughly altered rock of yellowish-gray color. This zone next to the wall represents the fine detritus accumulated on the foot wall and cemented by quartz. In the main quartz mass are several fragments of country rock in different degrees of alteration. The sharp outlines of the fragments, especially of the one in the lower right-hand corner, show that change in form or rounding of corners does not necessarily accompany the metasomatic process. In most of the fragments is also shown in all degrees a tendency toward replacement by arsenopyrite as a last step in the metasomatic process, as well as an inclination of the pyrite to crystallize around the fragments. The pieces of country rock, it is held, fell into the forming quartz mass simultaneously with its deposition. To some extent this bleaching of the black argillite is also shown on Pl. VIII, fig. *c*. The microscope shows this altered yellowish-gray rock to consist of a mottled mass of clear sericite fibers, between which lie clouded masses of fine grained calcite and some leucoxene (titanite). There are, further, abundant grains of pyrite and some arsenopyrite; in some places there are, with the pyrite, smaller masses of pyrrhotite, very strongly suggesting an alteration of the latter into the former. Many veinlets of carbonates are present, which as a rule contain little pyrite.

An analysis of an altered wall rock collected on the dump of the mine is recorded under IV in the table, p. 149. The rock analyzed is gray, with splintery fracture, contains many small veins of carbonates, as well as much pyrite; small grains of pyrrhotite are occasionally visible. The analysis, while characteristic of the metasomatic rocks of the gold veins, does not indicate a derivation from an argillite, but of a basic rock rich in titanium and magnesium, such as one of the numerous dikes contained at this vicinity in the prevailing rock.

The analysis may be calculated as follows, on the supposition that there is 7.75 per cent free silica present:

	Per cent.
Calcium carbonate	15.82
Magnesium carbonate	9.62
Iron carbonate	8.03
Pyrite	4.20
Quartz	7.75
Titanite	4.14
Apatite	1.82
Sericite	47.79
Water below 110°C	.30
Fe_2O_3	.17
	99.64

In this analysis there is enough carbon dioxide to form carbonates with all of the calcium, magnesium, and iron present. The sericite would, on the above supposition, have the following composition:

	Per cent
SiO_2	54.21
Al_2O_3	32.54
K_2O	8.96
Na_2O	.40
H_2O	3 89
	100.00

Pl. VIII, fig. *c*, represents in natural size a specimen from the old Banner mine (77 N. C.), showing well the shattering of the dark argillite by a network of quartz veins. Having been exposed to weathering, the carbonates containing iron have assumed a brownish color, which permits one to distinguish their frequent deposition along the sides of the veinlets, in contact with the argillite, instead of being mixed irregularly with the quartz. The argillite does not appear much bleached, but is filled by pyrite crystals, while there is no pyrite in the quartz. In thin section this lining of the fragments by calcite is even more characteristic, while the argillite is seen to be more altered in places than would be expected. Sericite fibers have developed in it, and small microscopic veinlets of calcite cut across it.

At the Osborne Hill mine the vein lies in porphyrite breccia, with abundant fragments of a sedimentary, brownish gray, fine grained rock. A specimen of the altered rock adjacent to the vein (83 G. V) has light gray color, is traversed by many small quartz seams, and contains sharp crystals of pyrite. The thin section shows an original extremely fine grained, clastic structure, chiefly of quartz grains, strongly recalling the argillite of Federal Loan; between the grains, and also in them, lie very fine felted aggregates of sericite fibers. The analysis confirms the microscopic evidence that the rock is derived from a siliceous argillite. The absence of carbonates in the altered rock is notable. The analysis No. VIII in the table, p. 149, may be calculated as follows, on the estimation of 50 per cent free silica:

	Per cent
Quartz	50.00
Sericite	46.24
Calcite	.26
Magnesite	.47
Pyrite	.56
Apatite	.34
Titanite	2 20
Water below 110° C	.30
	100.37

And the sericite would have the following composition:

	Per cent.
SiO_2	46.07
Al_2O_3	34.07
Fe_2O_3	1.67
FeO	.97
MgO	1.30
K_2O	10.55
Na_2O	.71
H_2O	4.66
	100.00

Analysis III shows the composition of the crushed rock from the foot wall of the Ural vein in the Providence mine It is a dark-gray, fine-grained rock with black, shining, and curved planes of schistosity and containing many small but extremely sharp crystals of pyrite. Under the microscope it is very different from the crushed granodiorite of the hanging wall of the same vein, the original structure being that of an allotriomorphic, fine-grained quartz-feldspar aggregate; this structure is now partly veiled by a development of sericite, carbonates, and chlorite. Besides these are many small crystals of an opaque mineral which may be magnetite. The analysis shows a great similarity to II, which is the crushed granodiorite from the Merrifield vein. The original material is, however, very different.

GOLD AND SILVER CONTENTS OF THE ALTERED WALL ROCKS.

As has been stated before, the wall rocks, replaced by carbonates, sericite, and sulphides, generally contain very little of the precious metals, even when adjoining rich ore shoots. A number of altered rocks were tested by Mr. C. Whitehead, assayer of the mint, with generally negative results.

	Gold.	Silver.
	Per cent	*Per cent.*
208 N. C., Providence mine (Analysis II)	None.	0.02
212 N. C., Providence mine (Analysis III)	None.	None.
148 G. V., Idaho mine (Analysis V)	None.	None.
22 G. V., Hermosa mine	None.	.30
104 G. V., North Star mine; near rich quartz	Trace.	.20
151 G. V., Empire mine (Analysis VII); near rich quartz	None.	.05

It is worthy of note that the silver predominates, while in the quartz the contrary is the rule.

CHAPTER XI.

VEIN STRUCTURE AND PAY SHOOTS.

STRUCTURE OF THE VEINS.

The character of the fissure determines, to a great extent, the structure of the vein. The simplest form of a fissure is a joint plane, such as is seen in regions of intense sheeting about the Lecompton and Canada Hill mines or in the seam belt of the Red Hill west of the Nevada City mine. On some of these joints there is a narrow line of quartz, accompanied by a slight bleaching of the rock on each side. Certain of these breaks along the joint planes may be more pronounced and extensive, or one larger break may be produced instead of a series of smaller ones. In such case there is usually a more noticeable movement along the fault plane, and the sliding of two irregular surfaces on each other produced more or less continuous open spaces, which were subsequently filled with quartz. This is the character of the Idaho-Maryland, the Mountaineer, and the Omaha veins, for instance, and is well illustrated by Pl. XI. The vein here consists simply of a filling of white quartz 2 to 3 feet wide between two parallel surfaces. The regularity is usually not maintained over a large extent of the vein. It is extremely common to find local pinches, and sometimes the vein is found to close down to a mere seam in whole levels, above and below which good ore is found. Again, in places the vein loses its regular character by reason of local fracturing and brecciating of the hanging wall. A typical occurrence of this kind is shown on Pl. XII (see also detailed descriptions, Idaho vein, p. 229). To this first relatively simple type many veins in the district belong.

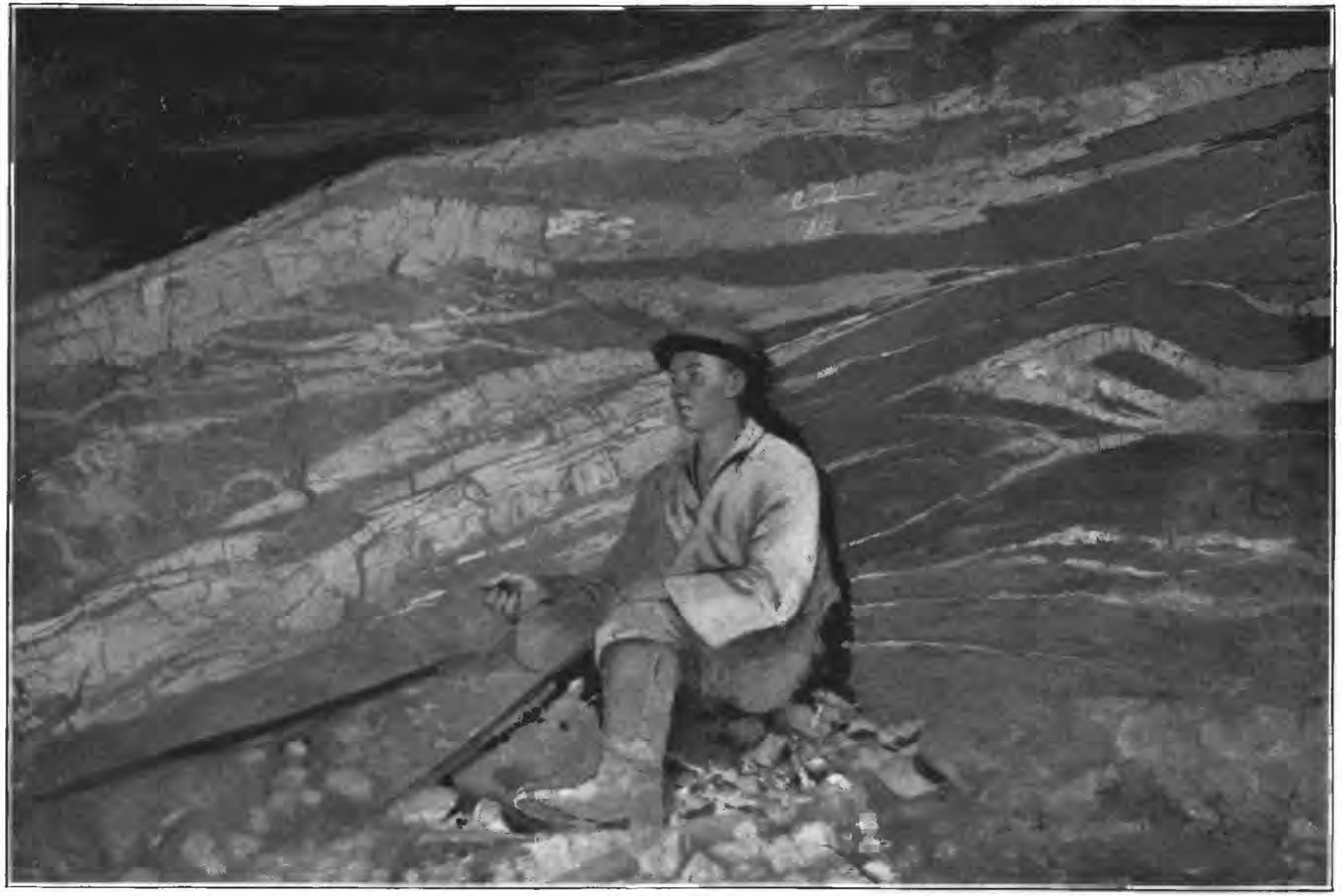
Another class of veins, to which the Empire, the North Star, and many others belong, presents a somewhat more complicated structure. In them the simple clean break is replaced by a compound one, in which two or more distinct fractures have been formed at a distance of a few feet; between these lies more or less crushed and brecciated rock. Quartz-filled fissures lie along the hanging wall or along the foot wall, or along any minor break in the rock between the walls. The latter may more or less distinctly assume the character of a breccia cemented by quartz. It is usual, however, to find the main quartz vein close to the hanging wall. The rock between the walls is always most altered by metasomatic processes. The little veins and seams, sometimes, as on Pl. XIII, forming a network in it, are predominantly composed of calcite. This structure is illustrated by Pls. XIII, XIV, and XV. See

MARYLAND VEIN, ON THE 1,400-FOOT LEVEL.

Vein 2½ feet thick and very rich.

MARYLAND VEIN, STOPE ABOVE 1,500-FOOT LEVEL.

NORTH STAR VEIN, NEAR 1,700 FOOT LEVEL, SHOWING 2-FOOT QUARTZ VEIN AT HANGING WALL AND ALTERED DIABASE WITH CALCITE SEAMS BELOW.



NORTH STAR VEIN, NEAR 1,800-FOOT LEVEL, SHOWING QUARTZ VEIN IN BRECCIATED AND ALTERED DIABASE.

OPHIR HILL VEIN, EMPIRE MINE, NEAR 1,800-FOOT LEVEL, SHOWING SEVERAL SMALLER VEINS BETWEEN FOOT AND HANGING WALLS.

BUNKER HILL VEIN, AMADOR COUNTY, CALIFORNIA; STOPES ABOVE 300-FOOT LEVEL, SHOWING VEIN SPLIT UP INTO SEAMS IN BLACK, CRUSHED CLAY-SLATE.

also fig. 18, Pittsburg vein, p. 202. The hanging wall is generally more distinct than the foot wall.

In the examples mentioned thus far, the evidence of extensive movement along the vein is less pronounced, the brecciated structures indicating a sudden short break rather than a long-continued grinding of the walls against each other. Schistose structure, due to the latter condition, occurs in places—for instance, along both walls in the Idaho-Maryland and the North Star, but only in the Ural and Merrifield veins does it becomes prominent. In these the quartz, where the vein is simple, is adjoined by several feet of schistose rocks, produced by the pressure and movement along the fissure; where the vein is compound, smaller streaks and seams of quartz are distributed through this schist, which may attain a width of 20 feet or more.

The width of the quartz vein may in some cases attain several feet. On the Merrifield vein a width of 6 and 10 feet of solid quartz has been observed, and in the Ural vein, in the Nevada City mine, one smaller ore body reached 12 feet. Ordinarily 2 to 3 feet is the width of the Merrifield and Ural veins. The other veins in the Nevada City district will not average 2 feet in width. With a few exceptions, the veins in the Banner Hill district are narrow, averaging hardly more than 18 inches. The Grass Valley veins are narrow, excepting the Idaho-Maryland, Gold Point, and a few more, and scarcely average 18 inches in width. Many veins, such as Houston Hill and Norambagua, have paid well with an average width of 6 inches, or even less. Seams with only an inch or two of quartz will sometimes contain an extraordinary amount of gold.

In the comparatively soft black slates of the Mariposa formation, along the Mother lode, a vein structure frequently appears, which, though not occurring in the region described, may be mentioned for comparison. The vein lies along the contact of black slate and diabase, separated by a distinct, and often polished, hanging wall of the latter. There is rarely a continuous and well-defined vein, but the black slate is crushed, sometimes over a width of 20 feet, or even more, and stringers of quartz penetrate it in all directions, in the manner shown on Pl. XVI, from a photograph by Mr. N. W. Emmens. Again, the pay is contained in the quartz, but it is, of course, necessary to mine the whole width of the stringer zone, which thus furnishes large masses of a low-grade ore. The plate shows, in addition, a curve of the principal mass of quartz, which may be due to movement subsequent to deposition.

THE PAY SHOOTS.

GENERAL FEATURES.

The rich quartz may occur in entirely irregular patches and areas on the plane of the vein. It is much more common, however, to find it occurring in more or less regular bodies, usually referred to as "ore shoots." Extremely rich masses of small extent and irregular form are called "pockets," or when they have a regular, long-drawn form, "chimneys." Pockets with local accumulation of coarse free gold often occur in the pay shoots of the Grass Valley mines; the Peabody and also the Gold Hill mines in Grass Valley, the Sneath and Clay and the Mohawk near Nevada City are examples of such pocket veins. The quartz between the pockets may be almost barren or it may contain a fair-grade ore.

In most of the veins the development of quartz is not confined to the ore shoots. In other words, the vein preserves its general character over a large area, but only in part of it—the ore shoot—does the quartz contain enough gold to be extracted as an ore. In another and smaller class of veins, represented by the Nevada City, the Omaha, the Pittsburg, and others, all quartz occurring in the vein is good ore, and outside of the ore shoots the vein closes down to a seam. The question what grade of quartz is regarded as ore of course influences the extent of the shoots. In the districts here considered, everything above $6 per ton, the average cost of deep mining and milling, is included as ore, although in most mines this tenor is considerably exceeded.

FORM OF THE SHOOTS.

A few characteristic ore shoots are shown on Pls. XVII and XVIII, and others will be found in the detailed descriptions. In general, the shoot has an elongated shape, and forms an angle with the horizontal plane, which generally differs, though usually not greatly, from the dip of the vein. In other words, the shoot usually pitches at a steep angle on the plane of the vein. The following law appears to govern the general direction: *The shoot will, as a rule, pitch to the left of an observer standing on the apex of the vein and looking down in the direction of the dip.*[1]

In a number of veins there is, to be sure, no great regularity, or the ore shoot will often be found to dip at the same angle as the vein, but the number of instances in which the above rule is applicable renders it indubitable that this occurrence of the ore is the result of certain conditions as yet not fully understood. This law holds good in a great many mining districts of the Gold Belt outside of these here described, and it is certainly worthy of close scrutiny. Pay shoots dipping in opposite direction from that stated above are said to occur on the Gold Flat vein, the Slate Ledge vein, and the Little Diamond vein.

No relation could be established between the direction of the pay shoots and the direction of the striation on the walls. According to the so-called Clayton's law, they should coincide.

Pay shoots may cross from one formation into another without change. As examples may be cited Providence mine, Merrifield vein, in the Nevada City district; Union vein, Banner Hill district; Empire vein

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[1] While this law has been well known by the miners for many years, yet it has not been distinctly stated before. In Bean's Directory it is applied to the north-and-south veins only (p. 55, Statement by T. H. Rolfe).

and Granite Hill vein, Grass Valley district. The apex of most of the large pay shoots discovered very naturally crops on the surface, but this is not an invariable rule. The apex of the Eureka-Idaho shoot, for instance, was found at a depth of about 100 feet; the beginning of the main ore shoot of W. Y. O. D. was not found till a depth of several hundred feet was reached; neither did the rich shoot on the Ural vein in the Providence appear on the surface. The possibility of finding a new ore shoot at any depth must be conceded.

While the largest ore shoots may be from several hundred up to 2,000 feet wide and up to 3,000 feet long, there are many shoots on the smaller veins which have a much less width and length. These smaller shoots sometimes go down to great depth, but are in general less to be depended on for permanence in depth than wider ore bodies. Even the small chimneys and pockets in the seam belt of Red Hill are stated to follow the law stated above.

The North Star workings (Pl. XXIII) form an excellent example of a large ore shoot following the same law. In this case the main shoot is composed of a number of smaller ore bodies with similar trend, separated by spaces in which the vein has closed down to a seam. The Eureka-Idaho ore shoot (fig. 27, p. 229) is unique in its long extent and flat dip; this is also probably the most uniform shoot in the district, containing relatively few barren places or pinches and having a known length of over 3,000 feet. No relation of the ore shoots to the cross fissures could be found. Indeed, the latter are generally later than the ore fissures and do not carry quartz. Intersection of two veins—a phenomenon not very often observed—will sometimes, but not always, produce richer ore bodies.

PERMANENCE IN DEPTH.

This question is one of the highest importance, bringing up the whole future of the industry of gold mining.

It is certain that the experience with many of the smaller bodies of ore is that they give out or pinch at varying depth.[1] Others, again, have continued to the greatest depth at which the exploitation of the mines has been carried on. Similar relations prevail in regard to the large ore shoots. While some have been found to cease in depth—the Sierra Buttes mine, in Sierra County, being a well-authenticated example—others continue to the deepest levels as strong as or stronger than in the upper part of the mine, the Kennedy mine, in Amador County, being an example of the latter class.

The frequent local irregularities of most shoots make it very difficult to affirm, without extensive explorations, that the end of any certain ore body has been reached. Owing to the habit of immediately distributing all of the profit as dividends, reserve funds for exploratory

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[1] This discussion refers only to the ores below the zone of oxidation. It is well known that the ores above the water level are, from causes of local concentration, richer than those not altered, and an impoverishment may generally be expected below the water level.

work are seldom available, and a local impoverishment in a level has often been sufficient to close a good mine. Experience with the large shoots is still insufficient for safe generalization.

The ore shoot of the North Star extends for a distance of about 2,500 feet in depth, measured along the plane of the vein. When approaching the sedimentary area to the west, it was cut off or divided into stringers. Still, the explorations are scarcely extensive enough to affirm that its end has been reached; its continuation may be found, or a parallel shoot may be found in depth. In the case of the large Empire shoot a complication has arisen, due to a split of the main vein, reducing the tenor of the ore by dividing it on three veins. The Eureka-Idaho shoot has held its own remarkably well and uniformly over a distance of over 5,000 feet, though the richest part of it was probably found in the Eureka and the western part of the Idaho ground.

High-grade ore is now mined in the Maryland mine on the same shoot at a vertical depth of 1,500 feet, and a small ore shoot was found near the bottom of the Idaho shaft at a depth of 2,200 feet. As gold-quartz veins of fair grade occur near the summit of Banner Hill, at an elevation of 3,800 feet above the sea, or 3,500 feet above the bottom of the Idaho shaft, we have in this district within short distance a vertical interval of 3,500 feet within which there is no evidence of any gradual change in the character or quality of the ore. Again, in the vicinity of Washington, Nevada County, excellent quartz is mined 600 feet below the river level, in the Eagle Bird mine, and on the ridges north of the river 2,000 feet above the river level. In this distance there are no distinct differences in the quality of the ore.

Many smaller veins carry only one ore shoot, but in the larger fissures there are generally several of them. There is a strong probability that in such veins thorough exploration laterally or in depth will develop new bodies of ore if the one on which exploitation has been carried on is found to pinch out. The question will naturally arise as to whether, with increased depth and cost of mining, it will be a good venture to carry on the necessary dead work. This will have to be decided by the record of the mine and the character of the fissure.

It is generally conceded now that fissures are, comparatively speaking, surface phenomena, and that below a certain depth, where plasticity and flow of rocks under pressure come into play, open spaces can not exist. This limit Professor Heim, for instance, places at 16,000 feet, while Professor Van Hise, basing his consideration on the strength of rocks, arrives at 33,000 feet as the maximum limit for hard rocks in which fissures can exist. Even the lowest of these estimates far exceeds the depth of practicable mining. But it is not likely that all fissures continue until that limit. On a small scale the discontinuance of fissures may be observed in extensive sheeted outcrops. It is also an incontestable fact that many small veins[1] close up in depth, while

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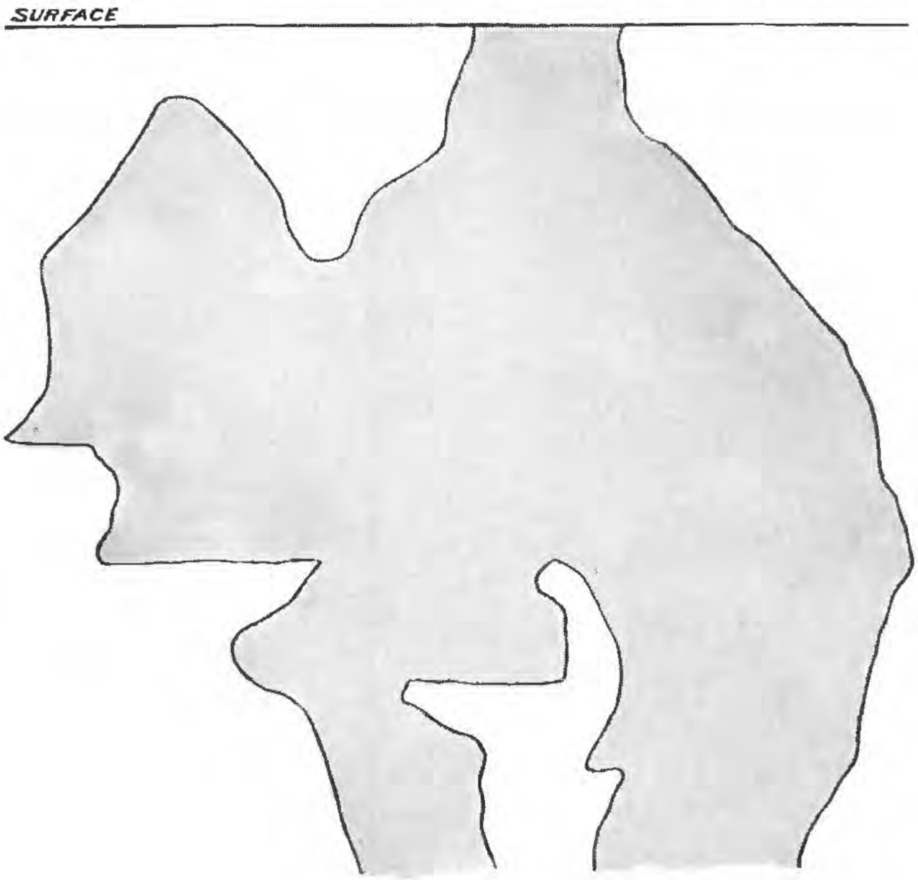
[1] These small fissures, though not continuous in depth, may easily have been accessible to the thermal waters by cross seams connecting them with the larger conduits.



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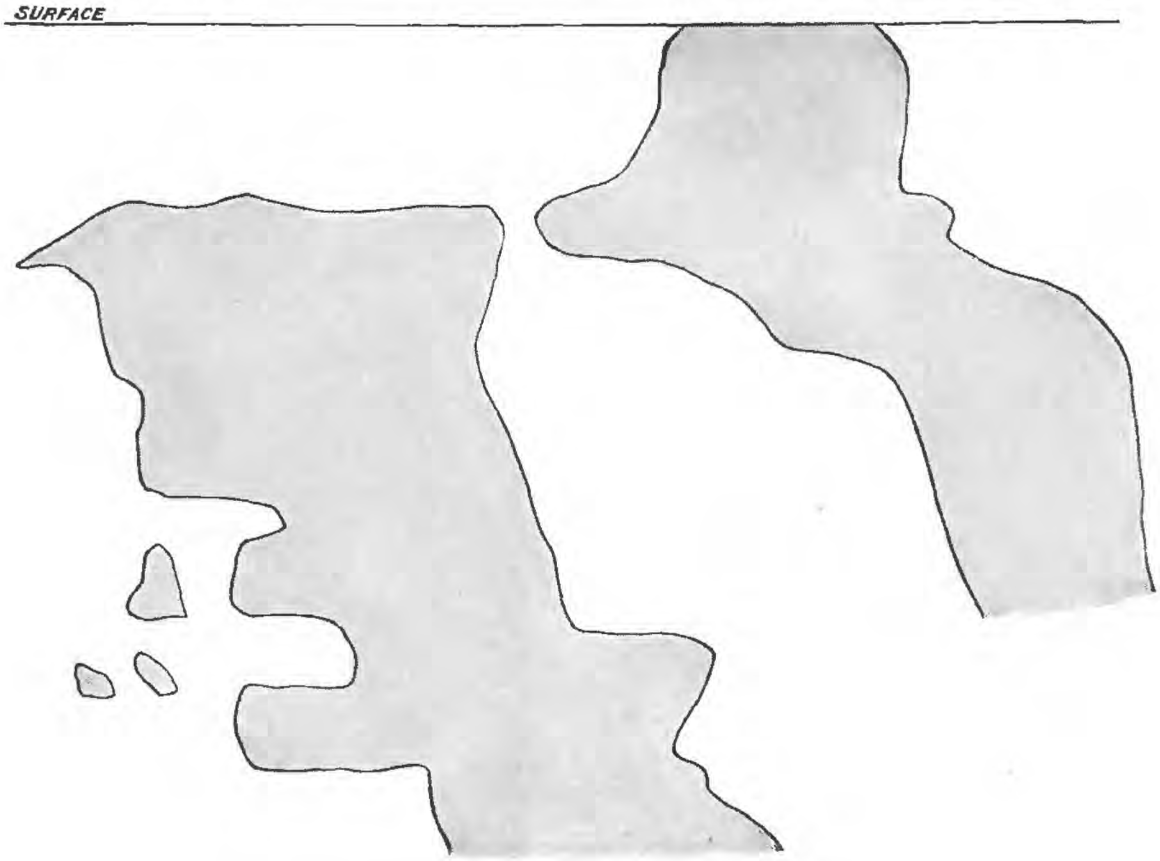
b

Scale
0 100 200 300 400 500 Ft.

ORE SHOOTS OF NEVADA CITY AND GRASS VALLEY MINES.



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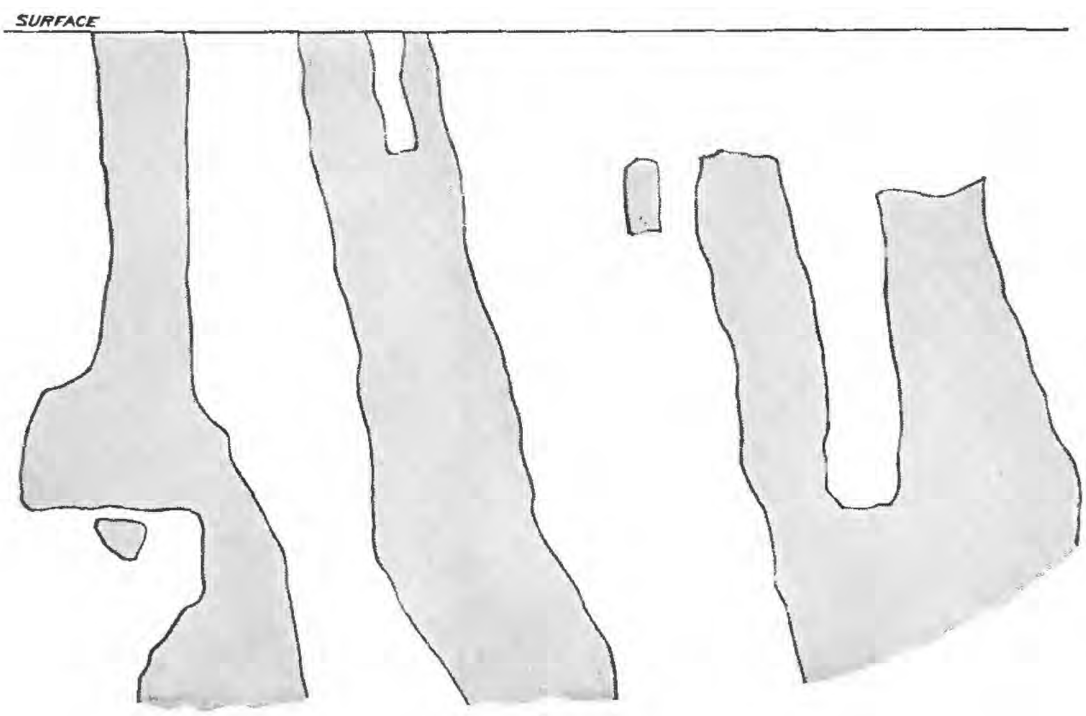

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Scale
0 100 200 300 400 500 Ft.

ORE SHOOTS OF NEVADA CITY AND GRASS VALLEY MINES.

others continue unchanged. In considering the probable permanency of a given vein, its general character must be taken into consideration. Continuous well-defined outcrops and wide bodies of quartz are in general good indications of the maintenance in depth, as is also any evidence of strong faulting and movement. Some quite extensive veins, though, have relatively short outcrops. Thus, the Eureka-Idaho practically shows croppings only for a distance of 2,000 feet, but within that distance they are very prominent. Those of the North Star are less than 2,000 feet long. From the developments to the east along the Omaha system it is pretty certain that the vein does not continue far across in that direction. A fissure which can be definitely proved to extend only a short distance will in all probability be found to be correspondingly limited in depth. In regard to probable permanency of the vein in depth, the Ural and Merrifield, along which extensive faulting has taken place, stand first in the districts.

In scrutinizing the scant statistics of the production, in tons and value, of the Grass Valley district, it can not be denied that they show on the whole a distinct decrease. There is also a distinct decrease in the average value of the ore. It is not safe, however, to draw too far-reaching conclusions from these data, because there are many factors involved: The cost of treatment and mining has decreased greatly by reason of the modern methods introduced, and more low-grade ores are now milled than formerly; nor are there any rich surface ores left to swell the grade.

Leaving the difficult question of deep mining out of consideration, there are, however, in both districts a large number of veins which have been only slightly developed, but which with improved methods may be converted into paying mines. The development of these will probably maintain the production of the district for many years in the future, even if no new ore bodies are discovered in the old mines.

It can be confidently stated that there is no gradual diminution of the tenor of the ore in the pay shoots below the zone of surface decomposition. Within the same shoot there may be many and great variations of the tenor, but there is certainly no gradual decrease of it from the surface down. This important fact has been previously stated by those conversant with the veins, such as Professor Silliman and Mr. J. A. Phillips. The statements to the contrary, for instance, by Mr. Laur or Mr. Reyer (see literature in Chapter I, pp. 16–17), are due to imperfect acquaintance with the facts and generalization from insufficient premises.

CROSS-CUTTING.

As a means of finding new and parallel veins, cross-cutting is frequently advisable, especially in those parts where strong sheeting of the rocks prevails. In the larger part of these districts, however, a series of parallel, distinct veins appear instead of the sheeting. These veins are nearly always traceable on the ground, and in such cases cross-cutting has rarely developed veins not known already on the surface.

CHAPTER XII.

THE FISSURE SYSTEMS.

That the veins are practically independent of the geological structure and that the strike and dip vary greatly are facts that have already been emphasized. However, certain systems with definite relations between one another may be easily recognized.

THE VEINS WITH A GENERAL EAST-WEST STRIKE.

Many of the most important deposits of the district are found on veins having a general east-west strike, which may be grouped in a number of subclasses:

The Willow Valley group.—This comprises the veins with moderate northerly or, more rarely, southerly dip (as the Federal Loan), occurring along Deer Creek, in the Banner Hill district, from the Texas mine to the Constitution. The strike is generally a little north of east. The central eastern part of this system is intimately connected with an extensive system of sheeting crossing the granodiorite contact. Nowhere, indeed, can the close connection of the veins with the sheeting of the country rock be better demonstrated, the veins simply forming the most prominent of the joint planes. The facts noted in the detailed descriptions of the Federal Loan and the Never Sweat mines indicate the intimate relation and contemporaneous origin of the veins dipping north and those dipping south. It will be suitable to designate groups of veins with the same strike but symmetrically opposite dip as *conjugated* systems.[1]

A line of veins with east-west strike and moderate to flat southerly dip extends from the Mayflower and Beckman to the Mohigan, south of the granite contact, and evidently belongs to this group.

The North Star group.—The strike in this group, which is developed only in the vicinity of the North Star mine, is generally WNW., and the dip moderately to extremely flat either north or south. The extremely intimate connection between the veins of these conjugated systems is again made clear by the developments in the New Rocky Bar (Pl. XXII), where two veins, one dipping north and the other south, join in a curved arch filled with quartz.

The St. Louis group.—Represented chiefly on the Banner Hill sheet by the St. Louis, Big Blue, and other veins, this group is distinguished by a strike about parallel to that of the Willow Valley vein, that is,

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[1] Daubrée, Géologie expérimentale, p. 320.

east-west or WSW.-ENE. The dip is, however, very steep, approaching 90°, and generally a little toward the north; the veins are often wide, but generally of low grade. In the Grass Valley district and in the vicinity of the Pittsburg mine and at other places in the Nevada City district there occurs a series of joint planes and fissures, rarely filled with quartz, which cut and sometimes fault the veins belonging to other systems. The dip is steep, to the north or south, and the strike in most cases ENE. It is probable that these "crossings," as they are locally called, belong to the St. Louis group. That they are still open fissures is indicated by the ease with which water circulates on them; they are, in fact, the principal subterranean watercourses, and in the vicinity where they prevail the deepest mines will drain all the smaller ones in the neighborhood.

The Idaho-Orleans group.—This important division is characterized by a strike varying between east-west and WNW.-ESE. and a steep, generally southerly, dip. The latter is, however, sometimes also at steep angles to the north, and, indeed, the Eureka vein is said to change from a southerly to a northerly dip in its western extension. The veins belonging to this group are strong, wide, and well defined. The Idaho, Orleans, Coe, Gold Point, and Imperial (on Deer Creek, west of the limits of the sheets) are illustrations. In which group the Spring Hill, Alpha, and Kentucky should be counted is doubtful. Toward the east the veins belonging to this group acquire a more decided northwesterly strike. In this group again, as in the others, there are indications of two conjugated systems with dips in symmetrically opposite directions.

THE VEINS WITH A GENERAL NORTH-SOUTH STRIKE.

To this class the majority of the veins belong, both in the Nevada City and the Grass Valley district. While the strike may be subject to variations extending from NNW. to NNE., there does not seem to be any reason for separating these veins into more than two groups.

The Providence group.—Dip, medium to flat to the east. These veins are represented in the Banner Hill district by the Banner Hill system, as well as by the Buckeye, Grant, Enterprise, and others. In the Nevada City district they are extensively represented by many smaller veins and by the important system of six or seven veins, radiating from a point near Town Talk toward NNW. and NNE. and then again all bending toward NNW. The Ural vein makes the most sudden bend, changing to a direction practically parallel to that of the Orleans-Idaho system. The Ural and Merrifield veins are among the most important in the district, and extensive faulting has without doubt occurred on them.

In the Grass Valley district veins dipping east at flat angles are found on Gold Hill, Massachusetts Hill, and along the foot of Osborne Hill. They are generally narrow and often very rich. Sheeting parallel to this group is noted along Wolf Creek at the Larimer mine.

The Omaha-Empire group.—Dip, medium to flat to the west. This group is also of great importance. In the Banner Hill district it is represented by the Deadwood, Murchie, and Canada Hill veins, at the latter place accompanied by extensive sheeting of the granodiorite; in the Nevada City district only a few larger veins, such as the Sneath & Clay and the Mohawk, dip to the west, but in the seam belt of Red Hill, west of the Nevada City mine, a great number of seams and narrow veins dip in that direction. The direction has been, however, changed so much to the northwest, following the great bend of the Ural vein, that the identification with the north-south class of veins becomes doubtful. In the Grass Valley district this group is abundantly represented by the Dromedary vein, continued southward by the Omaha system, and by the great Empire-Osborne Hill system of linked veins, in which the general direction has changed to some degrees west of north. Extensive sheeting parallel to this group of veins is shown in the northwestern part of Grass Valley (Pl. III).

Considered together, these two groups may again be regarded as conjugated systems of fractures. The exposures at certain mines, such as the Pennsylvania and W. Y. O. D., show the very intimate connection existing between the two groups and their contemporaneous origin, the quartz veins of one group sometimes falling back on fissures belonging to the other.

In each of the different groups of the east-west veins, as well as in the north-south veins, there are thus two conjugated and apparently contemporaneous systems with approximately similar dip in opposite directions.

INTERSECTION, FAULTING, AND RELATIVE AGE.

Intersection and faulting are not of frequent occurrence, and the opportunities for examining such phenomena from personal inspection are not abundant during one short season of investigation. The following facts are gathered from the detailed descriptions:

Veins of the Willow Valley group fault the Deadwood vein, which dips to the west, producing a reversed fault.

The Big Blue cuts through the Lone Star vein, dipping west. The St. Louis vein faults the Canada Hill, dipping west, and the fault is again a reversed one. Several east-west veins about parallel to the St. Louis fault the Floyd, dipping east, and the Beckman, dipping south. The movement is apparently a relative down-throw of the south side, diagonally inclined toward the east.

The Nevada County and the Mountaineer veins are faulted by east-west veins. The Pittsburg and the Gold Flat veins are repeatedly cut and somewhat faulted by perpendicular east-west seams, resulting in a relative downthrow of the north side.

In the Grass Valley district the barren cross-seams with steep dip and ENE. strike frequently fault the veins of the Empire and North

Star groups a little, the movement being generally in the nature of a reversed fault. A bending of the faulted vein is very frequent.

The faults are sometimes effected by single fault planes, but it is more frequent to find several parallel planes a short distance apart, on which gradually decreasing differential movement has taken place.

Summing up the evidence, the results obtained are:

That the north-south contemporaneous conjugated systems are the oldest veins;

That the veins of the St. Louis group are the most recent, and that the Grass Valley "crossings," though not as a rule filled with quartz, belong to this group;

That the veins of the Willow Valley group are more recent than the north-south veins, but older than the St. Louis veins;

That the North Star group is probably contemporaneous with the Willow Valley group;

That there is no direct evidence of the relative age of the Orleans-Idaho system, but that it is probably of the same age as the north-south veins;

That reversed (overthrust) faults, with a relative upward movement of the hanging wall, are prevalent. In the Merrifield and Ural veins the throw measured along the hade of the fault probably exceeds 1,000 feet, while in all other known cases the displacement is relatively small, possibly excepting the Idaho-Maryland vein.

RELATION OF THE VEIN SYSTEMS TO GEOLOGICAL STRUCTURE.

Considered in detail, no connection can be said to exist between the distribution of the veins and vein systems and the geological structure. Veins of the different systems occur in practically all the diverse rocks and cross all principal contacts without being influenced by them. They do not, as a rule, follow any contacts except where subsequent faulting has made the plane of the vein the contact plane. From this statement should, however, be excepted certain veins in serpentine, such as the Kentucky and in part also the Eureka-Idaho, which show an inclination to follow the line of diabase dikes in the first-named rock.

The veins do not, except locally, follow the schistosity in strike, and apparently never in dip. The different degree of resistance of rocks to deformation of course influences the fissures to some extent, but considering the great diversity of rock types this influence must be characterized as slight.

The fissures are more apt to be straight and clear-cut in hard, even-grained rocks, such as diabase and granodiorite, being splintery and irregular and easily breaking up into brecciated zones in argillite. Fissures in serpentine rarely continue unbroken for a long distance; in fact, to enter serpentine seems fatal to the continuation of most veins.

It might be said in a general way that the veins of the Willow Valley group are narrow and contain rich ore, much sulphurets, and a considerable percentage of silver, but certain north-south veins in the same district have the same characteristics. The Idaho-Orleans group may be characterized in general as heavy veins with but little sulphurets and little silver. On the whole, the rules which might be adduced are very vague and indefinite.

Nor can any distinct influence of the country rock be said to exist. Veins occur in granodiorite, diorite, gabbro, pyroxenite, and serpentine; in diabase, porphyritic diabase, and porphyrites; in amphibolitic, chloritic, and micaceous schists; in clay-slate, sandstone, siliceous argillite, and contact breccias. In scrutinizing closely the data in the detailed description it is found that the metasomatic processes have been practically identical in all these rocks, and that the character of the filling—that is, the principal ore—varies greatly, but is not constant for the same rock; it even varies in different parts of the same vein in the same rock. Veins in granodiorite and argillite often carry much sulphurets and silver, veins in diabase little of these substances, and of the former chiefly pyrites and galena. But these tentative rules have so many exceptions that their value becomes extremely problematical.

On the other hand, the influence of *locality* is strongly pronounced. The Willow Valley and Canada Hill veins form one group, the City veins another, the Providence-Mountaineer veins still another. The southern end of the Osborne Hill system is characterized by arsenopyrite, as are the Forest Spring veins, in greatly differing rocks.

Leaving the details and looking at the occurrence of the gold veins at Nevada City and Grass Valley, together with those of the surrounding country, the great concentration of deposits in the district described is the first striking fact.

To the west there extends down to the foothills vast areas of granodiorite, diorites, and porphyrites, in which only scattered quartz veins occur. To the south the almost barren augite-porphyrites reach down to Auburn. Toward the north stretches the granodiorite massif of Nevada City–San Juan, containing many placer deposits, but few quartz veins. Eastward, finally, are the sedimentary clay-slates of the Calaveras formation, on which lie many placer deposits and which contain many small, scattered veins, but no important vein systems until the vicinity of Washington, 15 miles east, is reached.

Between these relatively barren areas and the crowded fissure systems of Nevada City and Grass Valley, filled with rich gold ores, the contrast is very strong. Considering the veins of Banner Hill and the Nevada City district as a whole, it can not fail to strike any observer that, while occurring in any of the several rocks of the vicinity, they are chiefly grouped along the semicircular contact of granodiorite with the older rocks.

To the south of this zone is a comparatively barren belt until the Grass Valley district is reached. Here again the veins show some relation to the smaller massif of granodiorite, occurring on both sides of it and in it along its whole extent.

ORIGIN OF THE FISSURE SYSTEMS.

The first point emphasized by the study of the veins is the practical identity of the joints and sheets with the vein fissures, the only difference being one of degree of dislocation. The second is that schistosity of the rocks adjoining the veins may to some extent be produced by the same forces which produced the veins and joints. A third is the fact that each group of veins contains two sub-groups, which, with the same strike, dip in opposite and symmetrical directions, the two sub-groups being designated *conjugated* fractures.

The explanations of the joints, fissures, and occasionally accompanying schistose structure appear to be furnished by certain experiments by Daubrée[1] and by the mathematical deductions of Becker.[2]

It is plain that the formation of joints and fissures and the movement produced on them are due to mechanical causes. Tensile stresses—contraction and dilation—can not, as shown by Becker, explain these phenomena, for they result in the formation of curved and broken, and not extensive plane, partings; the fissures and joints would be gaping and there could be no slickensides on the parted surfaces.

Torsional stress can, according to the well-known experiments of Daubrée, produce two main sets of fractures approximately at right angles to each other, and usually at nearly 45° to the axis of torsion, the minor fractures often showing divergent directions. This explanation has been proposed for fissure systems—for instance, those on which the metalliferous veins of the Hartz are found. A closer examination shows, however, that the fissures produced by the experiments are nearly always curved and warped surfaces, and not approximate planes, as are the fissures here under consideration.

Becker[3] considers the experiments on the torsion of glass equivalent to the application of a system of tensions peculiarly distributed, and that the fissures produced in any mass physically resembling glass will exhibit the peculiarities of tensional fractures, together with some marked characteristics of their own.

This theory rejected for the present case, the only adequate one remaining is that of direct pressure, according to which the joints and fissures are produced by shearing stress. This, indeed, appears to explain perfectly all the facts observed, and especially the frequency of overthrust movements or reversed faults. In Daubrée's beautiful experiment[4] on a mass of beeswax and resin two conjugated systems of joints and fissures were formed, making an angle of about 45° with the line of pressure, and similar results have been obtained by testing cubes of building stones. These conjugated systems, which are approximately at right angles to each other, reproduce very closely the north-and-south veins of the districts here considered, with the

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[1] Études synthétiques de géologie expérimentale, p. 316.

[2] Finite homogeneous strain, etc.: Bull. Geol. Soc. Am., Vol. IV, 1893, p. 13.

[3] The torsional theory of joints: Trans. Am. Inst. Min. Eng., February, 1894.

[4] Loc. cit.

exception that the lateral angle between the planes dipping east and those dipping west is generally somewhat less than 90°. The east-west fissure systems are more irregular, the angles between the two sets of planes varying from 20° up to nearly 180°, and are, at least in part, later than the former systems.

It is thus most probable that the fissure systems have been produced by a succession of compressive stresses applied in different directions, chiefly from east to west and from north to south.

In the study of this question the fact should be borne in mind that not only vertical but to some extent also horizontal displacements have occurred, as indicated by the often inclined direction of the striations on the wall. The schistose structure often accompanying the veins appears, in conformity with Becker's view, due to relative tangential movement in the same direction as the fissure, but not reaching the limit of cohesion of the rocks.

TEMPERATURE IN THE MINES.

But few of the mines of Nevada City and Grass Valley have reached a vertical depth of over 1,000 feet, and the temperature of the air in the upper workings ordinarily ranges from 55° to 60° F. The Idaho-Maryland has at present attained greater depth than any other, and it seemed of some interest to obtain data from it as to the increase of temperature in the lower levels, even if the methods adopted were crude by necessity. A 2-foot thermometer was procured from Mr. A. Lietz, of San Francisco, and by him carefully compared with a standard. The graduation was in Fahrenheit. The instrument was inserted in bore-holes 2 to 3 feet deep, the opening carefully stopped up, with the neck of the thermometer protruding, so that it could be read by drawing it out a few inches. The thermometer was allowed to remain till a constant temperature was registered, usually about half an hour. The tests were made June 14, 1894. A bore-hole was first made in the drain tunnel, 250 feet from the mouth and about 30 feet below the collar of the shaft. The hole was 3 feet deep and in gabbro, the rock being very damp. Temperature in drift, +57½° F.=+14.2° C. Temperature in bore-hole, +53½° F.=+11.9° C.

The next observations were taken in the face of the drift on the fifteenth level, 1,523 feet vertically below the drain tunnel. The deepest point attained in the mine is 2,151 feet below the drain tunnel, or 2,181 feet below the collar of the shaft, but no levels below 1,600 feet are now accessible.

A damp bore-hole on level 15 gave the temperature of +66° F., or +18.9° C. The water on this level had a temperature of +62° F., or +16.7° C.

Further observations were made in the stope 40 feet above level 15, or 1,483 feet below the drain tunnel. A wet bore-hole in quartz gave the same results as 40 feet below, or +18.9° C. A dry bore-hole in quartz gave a little higher result, +67¼° F., or +19.6° C. The air in the stopes had a temperature of +69° to +70° F., or about +20° C.

Taking the damp bore-holes in the drain tunnel and on the fifteenth level for comparison, we have an increase of 12½° F., or 7° C., in a depth of 1,523 feet. Supposing it to be uniform, this is equivalent to an increase of 0.82° F. per 100 feet, or 1.5° C. per 100 meters. In other words, it is equivalent to an increase of 1° F. per 122 feet, or 1° C. per 66 meters. This is probably the most nearly correct value for the increment. Taking, however, the difference between the dry bore-hole in the stope and the damp one in the drain tunnel, a difference of 13.75° F. in 1,483 feet, or of 7.7° C. in 452 meters, is obtained. This corresponds to an increase of 0.93° F. per 100 feet, or of 1.7° C. per 100 meters. In other words, it is equivalent to an increment of 1° F. in 107 feet, or 1° C. in 59 meters.

In discussing these results it should first be stated that the temperature of 53.5° F. of the rock obtained in the drain tunnel, 30 feet below the surface, is apparently considerably different from the mean annual temperature of the air. There are no temperature data available from Grass Valley so far as I know, but the records from Colfax, Cal., 14 miles away and at nearly the same elevation, viz. 2,500 feet, cover a number of years and give a result of nearly 59° F. An average annual temperature of 53° F. is not reached until at an elevation of about 4,000 feet. It is further clearly apparent that the increment observed is very small compared with the values usually obtained. Even assuming the larger increment of about 1° F. per 107 feet, the temperature would only be 91° at a depth of 4,000 feet.

Professor Prestwich[1] gives the mean increment for coal mines as 1° F. per 49.5 feet; for other mines, per 43.2 feet, and for artesian wells, per 50 feet. Different localities show, however, greatly diverging results. Professor Hallock found in the well at Wheeling, W. Va.,[2] 4,500 feet deep, an increase of 1° F. for 80 to 90 feet in the upper part of the well, and of 60 feet in the lower part. Mr. Alexander Agassiz[3] found recently in the Calumet and Hecla copper mine, Michigan, 4,700 feet deep, an average increase of 1° F. per 224 feet, or 1° C. per 122 meters. This is decidedly the slowest increase noted anywhere, but the temperature at a depth of 100 feet appears in this case to be much higher than the average temperature of the air in Michigan. If the latter is contrasted with the temperature in depth a much more rapid increase is obtained. It is to be hoped that more observations will be made on the temperature of deep mines in the Gold Belt. Many of them appear to have a remarkably low temperature considering the depth, and it was this observation that led to the experiments here recorded.

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[1] Proc. Royal Soc. London, Vol. XLI, 1886, pp. 1-116.

[2] Am. Jour. Sci., Vol. XLIII, 1892, p. 234.

[3] Am Jour. Sci., Vol. L, Dec., 1895, p. 503.

CHAPTER XIII.

GENESIS OF THE VEINS.

AQUEOUS DEPOSITION CERTAIN.

It has been established in former chapters that the veins occur on fissure systems in the rocks, produced by a compressive stress, and that these fissure systems are later than any part of the pre-Cretaceous rock system. The substances due to vein formation are shown to be in part country rock altered by metasomatic processes, in part fillings of pre-existing cavities, the ores proper consisting almost exclusively of the latter class.

It has been assumed that these substances are due to the action of aqueous agencies, or, more definitely, to certain solutions containing, dissolved, the various metals and elements which are now found on the veins. The formation of quartz veins by these agencies is now so generally accepted that it is only necessary to point briefly to the facts indicating such an origin, the only remaining alternatives being an origin by sublimation or by gaseous emanation. Among these facts are the character of alteration of the country rock, including the removal of certain elements, such as sodium, the formation of hydrous minerals, and the occurrence of extremely abundant fluid inclusions in the quartz.

Admitting the aqueous deposition as a fact, the problems offering themselves are the character of the solutions and their origin, as well as the cause of deposition.

CHARACTER OF THE SOLUTIONS.

The filling of the veins, and especially the metasomatic rocks accompanying them, gives direct evidence as to the character of the solutions. The quartz indicates, of course, that silica must have formed an important constituent of the solution. The abundant carbonates and sericite in the altered wall rock show that carbon dioxide or alkaline carbonates, probably also calcic carbonate as well as potassium, must have been contained in the water. A portion of cl ar, massive quartz without sulphurets, from the fourteenth level of the Merrifield vein, Providence mine, was examined by Mr. George Steiger for substances soluble in boiling water, with the result that small quantities of sulphates and chlorides were found, which in all probability were contained in the fluid inclusion of the quartz. Sulphates must evidently also have been contained in the waters. Sodium would also be expected from the vigorous leaching of this metal indicated by the metasomatic processes.

The analyses of the ascending waters found on the veins, noted in the chapter on the contents of the veins, are of interest as showing to some extent the character which, according to the above, would be expected of the vein-forming solutions. They are, to be sure, cold and weak mineral waters, lacking in the amount of carbon dioxide and hydrogen sulphide which the vein-forming solutions must have possessed, and perhaps more the result of the leaching of the already formed vein, but the relative abundance of the carbonates and silica is suggestive, as is also the small amount of chlorides and sulphates.

Waters which have exercised such a powerful metasomatic influence on the rocks in the vicinity of the veins and contained such large quantities of carbon dioxide as are required by the facts of the metasomatism, are not known to occur in nature except as ascending, usually thermal springs. That such was the character of the vein-forming solution is a conclusion toward which not only one but several lines of reasoning lead.

That the waters were thermal is also indicated by the depth at which the deposition must have been proceeding. It is quite clear that the cropping of the veins—their apex—at the time of vein formation must have been far above the Neocene surface. The amount of their pre-Neocene erosion is difficult to estimate; from the geological history outlined above it is apparent that vast masses of effusive rocks covered the region previous to the granitic batholitic eruptions, and that the veins were formed immediately after these intrusions of abyssal rocks. From these data a guess may be made that about three or four thousand feet represents the thickness of rocks removed; the deposition must thus have taken place at considerable depth, with a rock temperature at least approaching 100° F. Any ascending water at this depth must have had a still higher temperature.

The alteration of the country rock is confined to a relatively narrow zone on each side of the vein, and gradually diminishes in intensity with increasing distance from the vein. This would certainly tend to show that the vein-forming solutions did not penetrate whole rock masses, but that they were confined to the paths prescribed for them by the fissures.

In Grass Valley there is a series of fissures of slightly later age cutting the quartz veins. These fissures, called "crossings," are to a great extent open highways for the atmospheric waters which have been circulating on them for untold ages and still have not been able to fill them with quartz or ore. The existence of this open-fissure system is one of the strongest possible proofs against the theory of lateral secretion in its narrower sense, implying a leaching from the country rock by atmospheric waters and deposition of ore by these waters in the fissures.

ORIGIN OF THE METALS AND GANGUE.

Admitting that the vein-forming waters were ascending thermal waters, the next question is, whence they derived their load of dissolved substances. The above discussion shows that the leaching by surface waters of the country rock is wholly inadequate to explain the vein phenomena. But it might be supposed that the contents of the veins—especially the gold and metallic minerals—have been extracted from the immediately surrounding rocks by the intense chemical action which is admitted to have taken place. This explanation is, in the first place, wholly inadequate quantitatively, for it is inconceivable that the relatively narrow zone in which the microscope shows that alteration has taken place should have furnished the large quantity of gold occurring on the veins. In the second place, the occurrence of practically identical vein fillings in a dozen rocks of the *most widely differing character and age constitutes the strongest argument* that can be adduced against the immediate derivation of the gold from these rocks. Other facts, such as the change in character of the filling in one and the same rock, point the same way.

According to the analyses, barium is found in notable quantities in the granodiorite, and barite should, according to the theory of lateral secretion, be found on the veins. Yet no specimen of this mineral has been collected from any of the veins, and, indeed, in the altered country rock that has been exposed to the action of the solutions the small percentage of barium is only slightly decreased.

In the basic augite rocks grains of copper pyrites are of rather common occurrence, and copper has been found analytically in two of the examined diabases. According to the theory of lateral secretion, copper pyrites should be abundant on the veins, yet in many of the veins in diabase chalcopyrite forms an insignificant part of the sulphurets or is practically absent. Two substances have, however, unquestionably been abstracted from the altered country rock by the solutions, namely, silica and sodium; possibly also other metals, but the latter in quantities which are so small as to be of no significance for the vein filling.

RARER METALS IN THE ROCKS.

It is quite possible that one or several of the rocks of the district may contain gold and silver or other heavy metals, and it is to be regretted that circumstances prevented the contemplated extensive series of tests. The occurrence of copper in two diabasic rocks from Grass Valley has already been referred to. Mr. George Steiger carefully examined, without any results, the granodiorite from Shurtleff's barn, one-half of a mile ESE. of the post-office, Nevada City (also analyzed, see Chapter X), for rarer metals, using a solution of 10 grams in aqua regia. A coarse-grained diabasic rock with fresh augite from the area south of Banner Hill was also examined in a similar way, with no results (59 N. C.).

A series of assays was carefully made by Mr. C. Whitehead, the assayer of the mint, with a view of finding minute traces of gold and silver. The granodiorite from Shurtleff's barn, Nevada City, gave no results. The granodiorite from Kate Hayes Hill, Grass Valley (49 G. V.), contained no gold, but 0.2 ounce of silver per ton. From appearances this was thought to be a very fresh rock, but the analysis shows a little pyrite, and the microscope shows a decided beginning of sericitic and chloritic alteration. Fresh diabase from south of Banner Hill (59 N. C.) gave no result; nor did a uralitic diabase, containing a trace of copper and much pyrite, from Leeman's ranch, Diamond Ravine, west slope of Osborne Hill, Grass Valley. A somewhat chloritic diabase from the seventh level of the Idaho shaft, 20 feet from the vein, gave no results. A breccia of argillite and porphyrite with abundant pyrrhotite, occurring on the lower road just east of the little gulch 1,700 feet south of Banner Hill, was next assayed. It has been indicated above that this pyrrhotite is not due to the vein-forming agencies, but is of earlier date and contemporaneous with the dynamo-metamorphism of the Jurassic or Cretaceous igneous rocks, which, again, took place before the granitic intrusions. Pieces rich in pyrrhotite were selected, and a trace of gold and 0.4 ounce of silver to the ton were obtained. The locality is, however, nearly in the continuation of the veins appearing just west of the summit of Banner Hill, and it would be difficult to assert positively that it did not contain small seams and fissures along which the vein-forming solution could have penetrated, so that, while suggestive, the result is not decisive. The main difficulty in the way of these tests is to obtain satisfactory material, positively free from joints and seams, by which the auriferous solution could have been introduced.[1] A local segregation of pyrite, epidote, magnetite, and chabazite from the Star tunnel in diabase above the Omaha mine, which certainly also belongs to the phenomena of general metamorphism and not to those of the gold-quartz veins, was assayed (24 G. V.); it contains no gold, but 1.20 ounces of silver. It would be of interest to examine the quartzose sandstones of Grass Valley for gold, but here, again, the difficulty of obtaining satisfactory material is great.

Though fragmentary and unsatisfactory, these results seem to indicate that traces of gold are not common in the rocks of the district. They further seem to indicate that wherever anything is found it is silver and not gold which predominates, while the reverse is true of the veins. It is believed that both silver and gold occur in very minute quantities in nearly all rocks of the districts, and that the pyrite and pyrrhotite developed in them by metamorphic processes, not hydrothermal in character, contain this silver and gold as a concentration. But it is not believed that the bulk of the metals of the veins is derived

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[1] Pyritiferous amphibolites from the Ophir district, Placer County, gave similar results; for instance, 0.010 ounce Au and 0.240 ounce Ag: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1894, p. 263. It is believed that the pyrites in these rocks are due, not to vein formation, but to the general metamorphism preceding it.

from the rocks immediately adjoining the vein. Their origin must still be left an open question; but the probability is strong that they were dissolved from the more deep-seated parts of the granodiorite, which appears to form the foundation of the Sierra Nevada, and brought to the surface by the thermal waters, the whole process being the closing chapter, the last manifestation, of the abyssal granitic intrusions. In other parts of the world a probable connection has been established between acid rocks, such as granites, quartz-porphyries, and quartz-diorites, with the gold veins; and metallic, unquestionably primary gold, has been found in such rocks.

Further questions not yet solved are, first, the remarkable dependence of the gold-quartz vein on the extent of the *metamorphic* series, shown in the paper on the "Gold-quartz veins of California;" and second, why, if derived from deep-seated rocks, fluor and bor compounds should be so universally absent.

These views do not imply a derivation from extreme depths or from the hypothetical "barysphere." The thermal waters rising on the veins were doubtless surface waters from the higher portions of the range, which penetrated to a considerable depth before reaching the surface again, but a few thousand meters would probably be the greatest depths attained by them. It should be borne in mind, however, how extremely unsatisfactory our knowledge of the circulation of deep-seated waters is.

SOLUBILITY OF THE GANGUE MINERALS.

According to Fuchs,[1] amorphous freshly prepared silica is soluble in water to the extent of 130 grams per ton. The natural siliceous waters show, however, a far greater solubility; the Iceland geysers contain up to 606 grams per ton; Steamboat Springs, Nevada, 306, and the Yellowstone Park geysers up to 580. The silica in the latter is not precipitated by cooling, even to freezing point, when not exceeding 400 grams per ton, and, according to F. A. Gooch,[2] it is probable that the compound is not contained as alkaline silicates, but as free hydrated silica. Saturating the waters with H_2S or CO_2 did not produce precipitation.

Calcic carbonate is slightly soluble in pure water at ordinary temperature (200 to 360 grams per ton of water, Doelter). In water saturated with carbon dioxide the neutral carbonate dissolves under formation of bicarbonate at the rate of 0.88 gram to the liter, or practically 880 grams to the ton.[3] With a small percentage of sodic or magnesic sulphate the capacity for solution is nearly doubled.[4]

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[1] Doelter, Chemische Mineralogie, Leipzig, 1890, p. 189.

[2] Formation of travertine, etc., W. H. Weed: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 655.

[3] Roscoe and Schorlemmer, Vol. II, p. 208.

[4] T. Sterry Hunt, Am. Jour. Sci., 2d ser., Vol. XLII, p. 58.

RELATION OF SOLUBILITY TO INCREASED PRESSURE AND TEMPERATURE.

It is a widely accepted view that in general the decrease of pressure and temperature forms an important factor in the formation of mineral deposits by ascending hot springs. In view of this, it may be profitable to inquire how, as far as we know, the solutions of different substances are influenced by the increase of pressure and temperature.

It is proper to draw attention at the outset to the fact that the question is extremely complicated, for the presence of other substances, as a rule, affects the solubility of any given salt; so that the rules obtained from simple solutions of certain compounds may not be applicable at all for solutions of the same in mineral waters.

Pressure certainly affects the solubility of many substances, but the result may be either an increase or a decrease. The investigation of Braun[1] shows that the rate of increase (positive or negative) is a function of the pressure, temperature, heat of solution, and change of volume taking place in the solution. If contraction takes place, which is the less common case, there is in general a decrease of solubility.

Regarding silica, there are apparently no data available; deposition taking place from highly saturated solutions may be due to loss either of heat or of pressure.

In the case of carbonates, and especially calcite, pressure is said to increase the solubility in water saturated with CO_2, but only up to a certain degree, the maximum amount that can be dissolved being 3,000 grams per ton.[2] Sodic chloride shows only a very slight increase in solubility by increasing pressure. Sodium sulphate, common in the mineral waters, shows a distinct decrease in solubility.

The influence of temperature has been more extensively studied. It may be said that up to about 100° C. there is in general an increase in solubility, but recent experiments seem to prove that for many substances there is, in fact, after a certain point has been passed, a distinct decrease.

No results are known in regard to silica. Calcic carbonate shows a slight increase in solubility in pure boiling water, one part being soluble in 10800 cold and 8875 parts of boiling water (Fresenius).

On the other hand, Engel and Ville[3] have shown that increase of temperature decreases the solubility of carbonates, especially magnesian carbonate. Sodium sulphate shows, according to Gay-Lussac and others,[4] an increase up to 35°, then a sudden decrease and nearly constant solubility up to 100°.

The other sulphates show similar relations, according to Etard.[5] Sodic, calcic, and ferrous sulphates, for instance, increase in solubility up to between 60° and 120°, from which a gradual decrease begins,

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[1] Ostwald, Allgemeine Chemie, p. 1046.

[2] Roscoe and Schorlemmer, Vol. II, p. 208.

[3] Compte Rendu., Vol. XCIII, p. 340.

[4] Ostwald, Allgemeine Chemie, p. 1048.

[5] Ostwald, Allgemeine Chemie, p. 1052.

potassic sulphate alone increasing steadily up to 200°. Sodic chloride increases very slowly in solubility up to 100°. Applying the formulas of vapor-tension to the problem ot solubility, Le Chatelier[1] arrives at the result that, in general, the curve representing the solubility will rise up to a certain limit at 100° C. or 200° C., and then gradually sink again.

Assuming a mineral water emerging at the surface with a temperature near the boiling point and a gradually rising pressure and temperature down to a depth of several thousand feet, it becomes clear that we are not in the least justified in assuming a gradual and indefinitely extended increased solubility in depth, or, reversed, that conditions for deposition will gradually become more favorable as upper levels are reached. It is in fact more probable that for temperatures rising high above 100° C. and under increasing pressures there will be a decrease in the dissolving power of the waters, at least as far as the principal constituents of the water are concerned. In all probability the quartz veins here described were deposited from solutions at great depth below the surface, under strong pressure and at temperatures ranging perhaps from 100° C. up to 250° C. It is true, and the fact agrees with results previously stated, that at the mouth of the crevice deposits of many substances are formed by suddenly diminishing temperature, but it does not at all follow that a diminution from 200° C. to 100° C. will produce a result similar to that of cooling from 100° to 0°. Besides, the precipitation at the surface is very largely caused by the oxidizing influence of the air, escape of carbon dioxide, evaporation, reduction by organic matter, and algous growth.

SYNTHESIS OF GANGUE MINERALS.

Quartz has been reproduced by Chroustchoff, Doelter, Senarmont, and others from alkaline solutions of silica or by recrystallizing gelatinous silica. According to Doelter,[2] quartz can not be reproduced from aqueous solutions at a temperature below 250° C. The facts hardly appear to bear out this assertion. At Steamboat Springs there are vast masses of siliceous sinter which are distinct surface accumulations and scarcely can have been found at a temperature above 100° C.—more probably below. Yet this sinter consists of a mixture of prevailing opal and chalcedonite, with smaller masses of finely granular quartz, often with crystallographic outlines. Small quartz crystals are found in the silicified wood of the auriferous gravels, where the temperature can hardly have been very high at any time.

Opal or cryptocrystalline silica may be deposited at considerable depths, as its occurrence in several deep mines of Grass Valley indi-

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[1] Ostwald, Allgemeine Chemie., p. 1057.

[2] Loc. cit., p. 154.

cates. Doelter's experiment on the solubility of gold, recorded below, indicates the same fact.

The different carbonate minerals may easily be reproduced at ordinary as well as at higher temperatures up to 500° C. (Friedel).

SOLUBILITY OF GOLD.

Considering only the solvents common in mineral waters, it is found that gold is attacked by many of them. Egleston found a slight solubility of gold in sodic and potassic chloride, as well as in many other salts of less importance for the present purpose.[1] Doelter has lately found that gold is soluble in a 10 per cent solution of sodic carbonate heated forty-seven days in closed iron tubes at 200° to 250° C.; also in a solution of 125 c. c. water containing carbonic acid as well as 8 per cent sodic carbonate and 3 per cent sodic silicate. In this latter experiment the gold was dissolved at the rate of 21.5 grams per metric ton of water. In the first experiment 1.22 per cent of the gold used was dissolved, which, under the assumption that a similar quantity of water was used (not expressly stated in the original), would give a solution of 42.4 grams per metric ton of water. These figures correspond to a value of $13.39 and $26.28 per ton of water.

An extremely interesting feature of the last experiment was that upon opening the tube a few minute crystals of gold were found, which in all probability were newly formed, and further, that small crystal aggregations of quartz had formed, as well as a large mass of hydrous silicic acid in globular concretions. In this as well as the following experiment on sulphides the heating was carried on only during the day, so that the interruption of the process may have had something to do with the deposition of the newly formed substances.

Liversidge[2] also found that gold was dissolved by sodic silicate, but it is doubtful whether this reaction is of much importance, as it is not at all likely that the alkaline silicates can exist in the presence of carbon dioxide.

Previously to Professor Doelter's experiment Dr. G. F. Becker[3] had found that gold is relatively easily soluble in sodic sulphide (Na_2S), a solution containing 843 parts of the latter dissolving 1 part of gold at ordinary temperature. Gold also, according to Becker, dissolves at ordinary temperature in sodic sulphydrate and in solutions of sodic carbonate partially saturated with sulphydric acid.

SOLUBILITY OF SULPHIDE MINERALS.

Doelter found that pyrite, galena, antimonite, sphalerite, chalcopyrite (in part), arsenopyrite, and bournonite are to some extent soluble in pure water, when heated for almost four weeks in glass tubes to a

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[1] Trans. Am. Inst. Min. Eng., 1880, Vol. VIII, p. 455.

[2] Proc. Royal Soc. New South Wales, Vol. XXVII, 1893, p. 303.

[3] Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 433.

temperature of 80° C. About one-eighth or one-tenth of the remaining undissolved, finely powdered mineral was in addition usually found to be recrystallized. Pyrite was soluble at the rate of 1,000 grams per ton of solution, or 0.10 per cent. The solution of galena contained 270 grams of PbS per ton.[1]

According to the same authority, galena and pyrite are also to some extent attacked by water containing carbon dioxide.

Becker[2] found that pyrite is soluble in cold solutions of sodium sulphide. Ten cubic cm. of solution containing 1.0955 grams of sodium sulphide dissolved 0.6 gram of pyrite, the solution thus containing about 60 grams of pyrite per ton, or 0.006 per cent. Pyrite is also soluble in hot sodic sulphydrate, but not in cold, and is relatively easily soluble in cold and hot solutions of sodium carbonate partly saturated with hydrogen sulphide.

Similar results were obtained with the sulphides of mercury, copper, zinc, and, of course, arsenic and antimony. The sulphides of lead and silver could not be brought in solution, the former not even when heated to 100° C. in closed tube.

Doelter's[3] later experiments show that pyrite, galena, zincblende, arsenopyrite, chalcopyrite, and bournonite are all soluble in sodic sulphide by treating the finely powdered minerals for twenty-four days of twelve hours at a temperature of 80° C. in glass tubes. Quantity of mineral used, about 1 gram; quantity of liquid, about 40 to 50 c. c. Of the pyrite, 10.6 per cent was dissolved, corresponding to an approximate content of 0.2 per cent of pyrite in the solution. Galena is even more soluble. In comparing these large amounts with Becker's results it would thus seem that time is a very important factor in the solution of these minerals. In regard to the solubility of tellurium compounds, which evidently have a close relationship with the gold, there are no data available.

EFFECTS OF INCREASED PRESSURE AND TEMPERATURE.

In regard to the influence of heat and pressure upon the solubility of gold and sulphides, there are but few definite data available, and, in fact, the problem is much more difficult than that offered by the ordinary easily soluble salts. The experiments by Becker and Doelter indicate that heat, and perhaps also pressure, increases the solubility, but how far this increase extends is almost entirely unknown. It is not unreasonable to suppose that, as with other salts, this increase is not indefinite, but reaches a maximum and then again declines.

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[1] Tschermaks mineral Mittheil, 1889, Vol. II, p. 319.

[2] Loc. cit., p. 432.

[3] Loc. cit., p. 323.

SYNTHESIS OF THE SULPHIDES.

In discussing the solubility of the metallic minerals, especially the sulphides, it has been tacitly assumed that they might have been formed simply by separating out from their solvents by changes affecting the latter. This is certainly not the only way in which they could have been formed in the veins, as is proved by the relative ease with which most of them can be formed synthetically in the wet way, chiefly by the action of sodic or hydric sulphides on different salts. Pyrite, galena, chalcopyrite, argentite, tetrahedite, bournonite, and arsenopyrite have been obtained by Senarmont and Doelter in this manner. Pyrrhotite requires for its formation the presence of an atmosphere of carbon dioxide or of reducing organic substances, entirely preventing the change from ferrous to ferric salts.

This is interesting in view of its extensive presence in metamorphosed argillites (Federal Loan), and in view of its entire absence from the veins (excepting a seam of abnormal composition in the Crown Point mine). Even the veins in argillite (Federal Loan) do not carry it; the pyrrhotite of the metamorphic argillite, close to the vein, is also, remarkably enough, converted into pyrite.

Marcasite has not yet been artificially produced; nor has zincblende; wurtzite, the rhombic modification, however, Doelter succeeded in obtaining.

The reaction by which the oxides of iron or other iron salts are converted to pyrite by the action of hydric sulphide or sodic sulphide is evidently of great importance. This reaction was shown by Dr. G. F. Becker to have taken place to great extent in the altered country rocks of the Comstock lode, the pyrite being principally, apparently, derived from the ferrous silicates; it was experimentally verified by Doelter[1] in case of oxides and carbonate of iron. It is clear that the ferro-magnesian silicates and the magnetite in the wall rocks have furnished the greater part if not all of the iron for the pyrite in the altered rocks, while it is equally certain that comparatively little iron has been carried from the country rock in the vein.

PRECIPITATION OF THE GOLD.

There are many experiments recorded as to reactions by which gold could have been precipitated from its solutions.[2] Ferrous sulphate is one agent. This is, however, too complete and sudden a reaction to be supposed to have a general importance in the formation of the gold veins. Precipitation by organic matter in the wall rocks is another, and the black slates along the Mother lode have been extensively quoted as a suitable cause for the deposition of gold. There is reason to believe that the importance of this reaction has been greatly overestimated, if

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[1] Chemiche Mineralogie, p. 148.

[2] A. Liversidge, Proc. Royal Soc. New South Wales, Vol. XXVII, 1893, p. 303.

indeed it is of any importance at all. The carbonaceous argillite of the Nevada City and Banner Hill districts offers an excellent criterion, and it does not appear to have the least influence on the tenor of the quartz in that rock, while other veins wholly in massive rocks and far away from any carbonaceous matter may be much richer than those in the slate. Certain experiments by Wilkinson (1866), Cosmo Newbery, Skey, and Liversidge[1] show that pyrite and also nearly all other sulphide minerals, including galena and arsenopyrite, will precipitate gold completely from solutions of auric chloride of varying concentration. This reaction is probably of considerable importance, as it explains the strong percentage of gold usually contained in the snlphurets in a state of minute dissemination.

Many other proposed reactions might be cited, but they appear of questionable value in speculating on the particular combination in which the gold is contained in the water. According to the views of modern chemistry, watery solutions of salts, even when only moderately diluted, contain the solids in a state of dissociation. Salts of gold could probably not exist as such in the mineral waters.

MODE OF DEPOSITION.

In discussing the mode and cause of deposition, it must be acknowledged that we have to deal with data only imperfectly known, and that the conclusions drawn from them are not yet more than a theory. Bearing in mind all the facts adduced, it seems certain, however, that the deposition has been effected by thermal water containing carbonates, silica, and sulphureted hydrogen or sodium sulphide, and containing also measurable quantities of gold and metallic sulphides. It would carry us too far to discuss the origin of this water and the source of its constituents. On the whole, the views of Daubrée and Posepny seem the most reasonable explanation. In the words of the latter, "The ground water descends by capillarity through the rock interstices over large areas, to mount again through open channels at a few points."[2]

During their long descent to heated regions the waters had ample opportunity to dissolve the substances contained in the rocks, and in this case probably obtained their gold and other heavy metals from the granodiorite at great depth.

It must be confessed, however, that the large quantity of carbon dioxide and sulphureted hydrogen carried by many thermal waters is extremely difficult of explanation. During its downward course the waters can not have taken up CO_2; on the contrary, descending surface waters in a short time are deprived of their CO_2 by the forming of carbonates. It is not probable that extensive bodies of limestone occur in depth in this vicinity.

It has been shown that pre-Neocene erosion had removed a great

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[1] A. Liversidge, Proc. Royal Soc. New South Wales, Vol. XXVII, 1893, p. 303.

[2] Genesis of ore deposits: Trans. Am. Inst. Min. Eng., Vol. XXIII, 1893, p. 221.

deal, probably a couple of thousand feet at least, of the upper parts of the gold veins, and that the levels at which mining is now carried on were probably from 2,000 feet to 5,000 feet below the original apex. Within this interval there is certainly no change in the quality of the ore (excepting decomposition above water level), nor can it be said that a change in quantity has been definitely proved. Within the limits of explorations by deep mining no definite progressive change in the character of the ore or of the altered country rock has been found, such as would undoubtedly exist if the cause of deposition were decreasing pressure and temperature. From this, as well as from the results of the investigations of solubility of the different substances, it may reasonably be concluded that an undue importance has been attached to the rather seductive phrase "deposition by decreasing pressure and temperature," though it is not to be denied that the deposition may be in part a function of these variables.

The metasomatic action on the wall rocks is undoubtedly of great importance for the deposition. The facts stated several times before show that there is but very little free gold in the altered wall rock and very little gold in its sulphurets, while the main amount of the gold and the auriferous sulphides are contained in the quartz filling the fissure.

It may be possible to consider the walls as forming a septum permeable only for a part of the solution, according to the osmatic laws,[1] especially for the substances which act chemically upon the minerals of the rocks. The latter in general are shown to be permeable for the carbon dioxide and alkaline carbonates; also for carbonate of calcium; further, for hydrogen sulphide or sodic sulphide, and for arsenic sulphide. On the other hand, they are less permeable for silica and gold, and almost entirely impermeable for the other metallic sulphides. This suggests the possibility that the hydrated silica is contained in the water in colloidal solution. Sulphide of gold in colloidal solution, impermeable for the ordinary parchment membranes used in the dialyzer, has been prepared by Dr. E. A. Schneider.[2] It might possibly have existed in the waters, though the probability is that it would be decomposed by some of the constituents of the mineral waters. It is also known that the sulphides of the heavy metals in general can form colloidal solutions.[3] However, the properties of colloidal solutions are only imperfectly known, and it is doubtful whether crystallization could take place in such solutions.

By metasomatic processes the wall rocks absorb carbon dioxide, potassium, sulphur and lime from the vein solutions. On the other hand, there has been a steady acquisition of sodium (probably as carbonate) and of silica, abstracted from the wall rocks. The result of

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[1] Dr. G. F. Becker first introduced this conception applied to the mineral deposits, and it promises to be of great importance for the discussion of their genesis. See "Quicksilver ore deposits," in Mineral Resources U. S. 1892, p. 21.

[2] Bull. U. S. Geol. Survey No. 90, 1892. p. 56.

[3] Bull. Soc. chimique, vol. 48, 1887, p. 165.

the whole process would probably be a concentration of the vein solutions and progressive accumulation of silica. As far as the chief constituents are concerned, the vein solutions were very likely highly concentrated. The deposition of silica was probably partly caused by an unbalancing of the delicately adjusted conditions in a concentrated solution of different compounds by the new material from the wall rock, and partly by varying conditions of temperature and pressure.

The metallic sulphides and the gold carried by the silica were probably to a great extent precipitated mechanically by the crystallizing quartz. The intimate connection of the gold with the sulphides was very likely caused by the experimentally proved tendency of gold solutions to be precipitated by particles of sulphides.

The causes to which the occurrence, form, and direction of the ore shoots are due are very obscure, and to extend the discussion to them would be to go farther in the realms of hypothesis than is here desirable.

CHAPTER XIV.

DETAILED DESCRIPTIONS.

BANNER HILL DISTRICT.

VEINS OF THE DEER CREEK BASIN AND WILLOW VALLEY.

General features.—These veins have in general an east-west strike and flat medium northerly or southerly dip. The ores are frequently of high grade and the fissures narrow. The gold is associated with much silver, and there is a considerable amount of sulphurets. A few veins having a north-south strike and flat westerly dip intersect the

FIG. 10.—Sheeted zone in granodiorite, Deer Creek, Bellefountain mine.

prevailing system. The east-west veins are in closest genetical connection with a system of joints or a sheeting of the country rock; this sheeting begins to show very strongly a little beyond the Deadwood mine, and may be seen to best advantage all along the rocky canyon of Deer Creek. Fig. 10 illustrates this structure; granodiorite is divided in benches or sheets from 1 to 4 feet thick and dipping north at slight angles. Opposite the Bellefountain mine the strike is N. 78° E. and the dip 30° N.; at the Lecompton mine the strike is east-west and the dip 30° N. On the Federal Loan road opposite the big bend, 500 feet west of the contact, N. 68¼° E. and 35° N. was noted; here the sheeting seems most intense. In a width of 1 foot six or more minute seams were seen, dipping as stated, and each marked by a slight bleaching of the granodiorite and by a fine string of iron pyrite. The normal granodiorite does not contain any pyrite. This sheeting continues unbroken across the contact, but the direction swings a little more to the northeast and the dip becomes decidedly steeper, up to 68°. Besides the joints dipping north, another set now begins to appear, about parallel to the first in strike, but dipping south. In a fresh exposure of black, hard metamorphic rock on the ditch 2,000 feet east-southeast of the Federal Loan, the following directions were noted, the sheets being about 6 inches thick: (1) Strike N. 58° E., dip 70° N., and (2) strike N. 68° E., dip 60° S. The displacement which has taken place along these joint planes is probably in most cases very slight. Ascending waters have formed the most prominent veins along those fissures in this joint system which offered the easiest channel for their passage. There is always a strong possibility of finding veins parallel to and a short distance away from those exploited, and cross-cutting should consequently not be neglected in working the deposits in this vicinity.

The Federal Loan vein.—This is an old location, worked many years ago, but not opened on a larger scale until 1890; it has at present a 10-stamp mill, and the total output is stated to be $175,000.[1] The mine is developed by an incline shaft, following the vein down for a distance of 800 feet, and by drifts extending from 100 to 400 feet on each side. The mine is only a few hundred feet east of the granodiorite contact, and the country rock is that black or dark-brown, fine-grained, massive, siliceous argillite described in Chapter V. It is somewhat influenced by contact-metamorphic action, which has given it a slightly coarser texture and browner color, the latter caused by the development of biotite or brown mica. Dikes of coarse, dark diorite are met in the drifts of the mine. Pyrrhotite is distributed throughout the country rock in minute grains. The vein, which crops only near the shaft, strikes somewhat north of east and dips south at an angle of 45°. It is very irregular in width, sometimes showing several feet of massive quartz, then again closing down to a seam, or also frequently breaking up in a mass of stringers, which may be mined and milled as a whole on account of the gold contained in them. The wall rock itself contains but little gold.[2] The rock in the immediate vicinity of the vein is irregularly altered to a pale grayish material, often cut by small calcite veins, and containing much finely disseminated pyrite and arsenopyrite. This rock is examined more in detail in Chapter XI. The

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[1] Nevada County Mining Review.

[2] Cf. Eleventh Rept. State Mineralogist, p. 290.

hanging wall of the vein is not well defined, but the foot wall continues unbroken and distinct. Numerous seams dipping north at various angles, but carrying no quartz, are noted, as illustrated on fig. 11. The mineral spring on the fourth level is described in Chapter IX. The filling of the vein consists of the usual milky-white quartz, occasionally containing grains of calcite. Fragments of the country rock, sharp and angular, though converted into carbonates and sericite, are very frequent in the quartz, and around these fragments the sulphurets often cluster, as illustrated in Pl. VII, fig. *b*. The ore contains the large amount of 6 per cent of sulphurets, which have a very high percentage of arsenopyrite and are of medium grade, containing somewhat more gold than silver by weight. (For analysis of concentrates, see p. 127.)

Arsenopyrite and pyrite prevail, while galena, zincblende, and copper pyrites are very subordinate.

The ore shoots are somewhat irregular, but the best pay is found in a chimney in the vicinity of the shaft, dipping about 70° E. on the plane of the vein. The value of the ore is stated to be $15 per ton.[1] The gold is 675 fine.

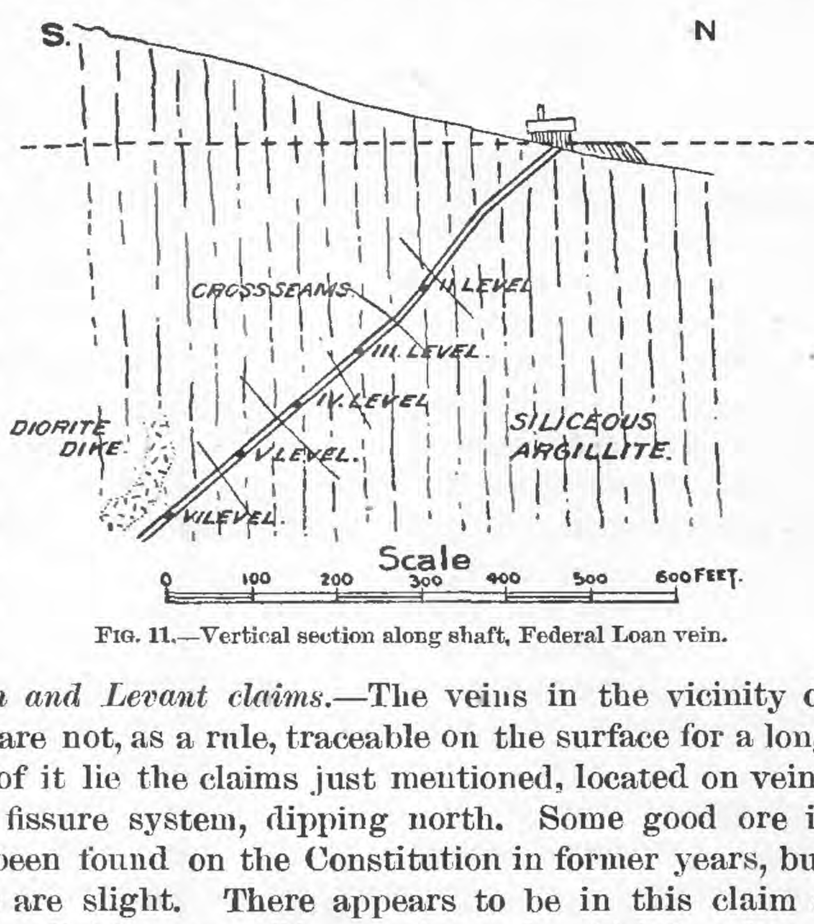

FIG. 11.—Vertical section along shaft, Federal Loan vein.

The Constitution and Levant claims.—The veins in the vicinity of the Federal Loan are not, as a rule, traceable on the surface for a long distance. North of it lie the claims just mentioned, located on veins belonging to the fissure system, dipping north. Some good ore is reported to have been found on the Constitution in former years, but the developments are slight. There appears to be in this claim a number of small parallel fissures. The country rock, which is a dense, siliceous argillite, is impregnated with iron pyrites along the veins. In the mint report of 1880 the vein is stated to be 1 foot thick, heavily sulphureted, and similar to the Lecompton.

The Lecompton vein.—The Lecompton is situated on the south side of Deer Creek, almost adjoining the Federal Loan. It was located in 1857, and up to 1863 the gross yield of the mine was $220,000. From 1863 to 1866 it was also a considerable producer; in 1867, however, the incline situated near the bed of Deer Creek was flooded by a freshet,

[1] Eleventh Rept. State Mineralogist.

the improvements destroyed, and no work has been done since then. It is credited in the mint reports of 1889 and 1890 with a production of respectively $5,350 and $900, which amounts probably came from remaining pillars of ore in the upper workings. The outcrop of the vein, owing to the flat dip, forms a curve high up on the slope; the ore in this part of the vein was decomposed and very rich, and has been extracted by means of numerous tunnels. Below the creek level the vein was opened by an incline near the east end of the claim, 275 feet long. There is also an incline 300 feet long near the western end. The vein is contained in granodiorite, strikes east-west, and dips 38° to 40° N. at the east incline. It is only from 4 to 8 inches wide; specimens show excellent comb structure. The gold near the surface had a fineness of only 650, while in the deeper workings it attained 750. The ore is stated to have contained arsenic and antimony, and was very rich, the upper parts of the vein averaging $40 per ton, and smaller lots running up to $400. According to the mint report of 1889, the bullion contained 416 per mille gold and 584 per mille silver.

Between the Lecompton and the Federal Loan lies the Lebel, a vein in granodiorite striking E. 23° S., dipping north, and opened by several short tunnels from the level of Deer Creek up on the side hill. The vein is up to 16 inches thick, of fair grade, and contains very abundant arsenopyrite.

On the north side of the creek, opposite the Lecompton, there are a great number of old slopes and tunnels run on narrow veins between the sheets of granodiorite.

The Bellefountain vein (formerly the Ebaugh).—This well-defined vein lies on the north side of Deer Creek, near the Lecompton. Located in 1857, it has been worked at intervals since then. It is opened only by tunnels run in from the steep slope of Deer Creek Canyon. The outcrop runs up the hill to an elevation of 270 feet above Deer Creek, and then crosses over into the Cyane claim; its direction is east-southeast, while its actual strike on a horizontal plane is east-northeast. The dip is 28° to 30° N. The vein averages 12 inches in width, and there are several small but rich ore shoots; no ore containing less than $24 is said to have been crushed.[1] This, as well as all adjoining veins, is in granodiorite. Close to the vein the fresh rock changes to a yellowish gray, soft mass of still clearly discernible granitic structure, consisting of sericite, some carbonate, residuary quartz, and abundant sharp cubical crystals of pyrite. (For description and analysis, see p. 149.)

Never Sweat and Omega veins.—These are veins parallel to the Bellefountain and located a few hundred feet farther north. The Never Sweat is opened by an incline 300 feet deep, has been worked only on a small scale, and is shut down at present. The information about it is obtained from Mr. J. Lyons. The country rock is a granodiorite with considerable hornblende, and decomposes to a reddish soil of great

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[1] Nevada County Mining Review.

depth, on account of which the outcrop can not be readily traced on the surface. The vein is narrow, from 3 to 16 inches, and yields some very high grade ore, the value sometimes reaching $300. Generally similar to the Lecompton, the bullion contains some antimony and much silver, being only 750 fine. The strike is N. 73° E., and the dip at first 45° N. At a depth of 200 feet a cross vein is struck, belonging to the Federal Loan system of fractures, and, according to Mr. Lyons, the vein leaves the original fissure and continues on the one dipping south (fig. 12). This is of great interest as proving that the two vein systems are contemporaneous.

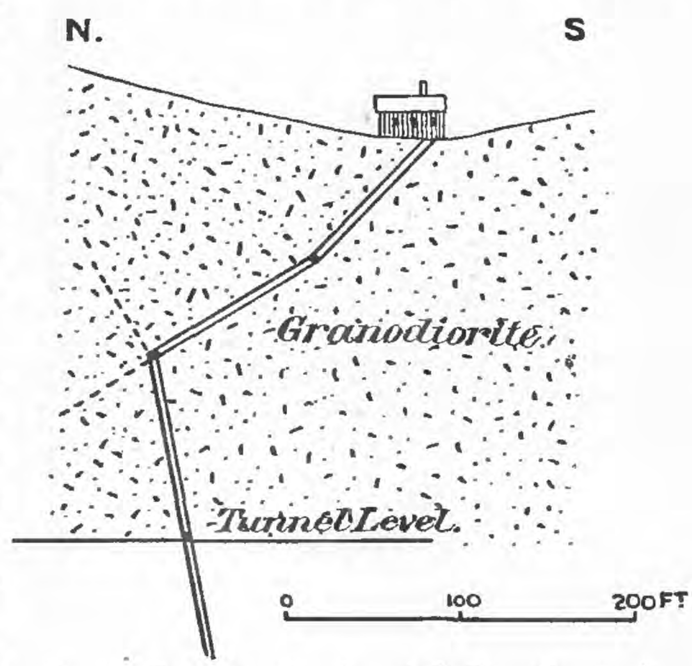

Fig. 12.—Vertical section along shaft, Never Sweat vein.

Near Willow Valley there are a considerable number of veins, none of which, however, have been worked very extensively.

The Montana vein.—This has been worked intermittently and has produced some good ore. It is developed by an incline shaft 400 feet long; strike northeast, dip 22° NW. The vein is from 6 to 8 inches wide, and can be traced for a considerable distance across the contact line. The ore, which is heavily sulphureted, forms two pay shoots pitching to the southwest on the plane of the vein, one on each side of the shaft and from 100 to 200 feet wide. In the claim are three more parallel ledges of less importance.

The Willow Valley vein (*Tolbert*).—Located in 1865, but little work has been done on this vein since 1867; 800 tons were taken out in 1866, yielding an average of $22 per ton.[1] It is developed by a 200-foot incline; the vein strikes northeast and dips 45° to the northwest; its width is from 1 to 4 feet. The country rock is granodiorite, the eastern end of the claim crossing the contact.

At the forks of the Washington and Scotts Flat roads is a small vein, striking N. 72° W. and dipping 70° N., on which a little work has been done.

The Franklin-Hussey vein.—Not much work has been done on this vein since 1884, when some very rich ore, going as high as $150 per ton, was produced. It is developed by an incline and drifts 230 feet long and extending 90 feet on each side. The strike is northeasterly and the dip 45° NW. The vein is in places from 1 to 2 feet wide.

[1] Bean's Directory.

The Buckeye vein.—This vein, which is opened by a 400-foot tunnel from Willow Valley Creek, has a northerly direction and an easterly dip of 45°, both unusual for this locality; it is inclosed in hornfels and is only a few hundred feet from the contact; the width is from 1 to 2 feet, and some good ore is reported from it. It can be traced from the creek northward until it disappears under the andesitic breccia.

The Deadwood vein.—This vein, which is located near the mouth of Willow Valley Creek on the north side of Deer Creek, has been a considerable producer at various times since 1856, but in the last ten years nothing has been done on it. A 10-stamp mill formerly existed on the property, and the total production is given by Mr. J. Lyons as about $300,000. The vein is opened by an incline shaft 500 feet long, a drain tunnel from Deer Creek, and several drifts extending principally southward of the shaft for 300 to 400 feet. The vein, which is in granodiorite, crops on the surface, where it is very flat, in a northeasterly direction. Its true direction, as shown by the incline and drifts, is N. 18° E., the dip being 25° W. The width is narrow, ranging from a mere seam to 18 inches. The ore is highly charged with sulphurets, carrying pyrites, galena, zincblende, and arsenopyrite, also containing some antimony. The tenor is high, sometimes reaching $100 to $200 per ton. Most of the ore has been extracted from the south side of the incline, while the northern side has been prospected but little. The bullion is 815 fine, which is more, it will be observed, than is usual in this part of the district. The croppings to the east of the incline, which over a large area lay extremely flat near the surface of the thoroughly decomposed granodiorite, have been extensively sluiced and even washed by the hydraulic process. According to Mr. Lyons, the vein is distinctly faulted on the tunnel level to an aggregate amount of 30 feet by four cross seams striking a trifle north of east and dipping 45° N. The vein was found to be thrown westward going north on the drift, which would indicate a reversed fault with relative upward movement of the hanging wall. The seams are comprised within 100 feet; in the lower workings the same seams were found a little closer together; without doubt they form the continuation of the Texas vein complex. The workings of the mine are not now accessible.

The Texas vein system.—About 1½ miles east of Nevada City, on the Willow Valley road, there is a strong system of at least four well-defined veins, named respectively the Creek, Wheal, New York, and Delaware (Red, White, and Blue). All strike about east-west and dip north at angles varying between 38° and 50°. The developments are slight, consisting chiefly of short tunnels from Mosquito and Deer creeks. The New York is opened by a 100-foot-deep incline (Texas mine). Some of the veins, especially the New York, are very heavy, 3 and 4 feet of solid quartz being met with; on the road a little east of the Texas mine the croppings are unusually strong; in the best pay shoots the ore from these veins runs from $8 to $40 and contains 4 per cent or more of sulphurets. The Delaware continues far eastward over on the Murchie ground. These veins seem to form the starting point for the Willow Valley system, the originally strong fissures being replaced eastward by an extensive system of sheeting.

The Murchie veins.—This complex consists of two east-and-west veins, the Big Blue and the Alice Belle, as well as two north-and-south veins, the Lone Star and the Independence. The property has been worked at various times since 1861, the principal producer being the Big Blue; from 1878 to 1884 the mine was one of the largest producers in the district and had an 18-stamp mill; detailed statements of its production are found in the mint reports. From 1884 to 1894 it was shut down but has lately started again, probably with the expectation of using electric power. From 1878 to 1884, 38,000 tons were crushed, containing $587,000, or an average of $15 per ton, with 4 per cent of sulphurets, at an average cost of $1.60 for milling and $6 for mining per ton. The sulphurets are very rich, containing from $100 to $300 per ton (Mint Report, 1883). The Big Blue is almost perpendicular, dipping 85° N., which is unusual in these districts. The vein is often very wide, even up to 4 and 5 feet, and consists of white massive quartz, which besides free gold contains iron pyrites sprinkled through it; tellurides are also reported from the vein (p. 117). The principal ore shoots on the vein dip west and appear to follow the lines of intersection with the flat veins. A decomposed porphyritic rock found on the dump of the Independence is said to come from a dike following the Big Blue for some distance. It is described in Chapter III, p. 47, and appears to be a lamprophyric dike rock.

The Independence is also a heavy vein, sometimes 2 or 3 feet thick. According to Mr. Murchie it was at the line of intersection *cut off* by the Big Blue, the latter passing through it without faulting to any extent. The Lone Star vein can be traced up to the old placer diggings, where it intersects the Alice Belle. Some good ore is reported from the latter.

MINES OF THE LITTLE DEER CREEK BASIN.

General features.—Aside from a few veins in the lower part of the basin, there are two centers in this part of the district where the majority of the veins are clustered, namely, Canada Hill and Banner Hill. At the former place a large number of smaller veins are contained within the angle of the two strong fissures of the St. Louis and the Orleans (Glencoe) veins. These smaller veins belong to several systems, one striking north and south and dipping west, another with the same strike but dipping east; there are also flat veins dipping south, and other east-west veins with a steep dip. This great complex lies, as the map shows, near the granodiorite-slate contact, but the veins show no relation to the latter, frequently crossing it without being disturbed. Further, though individual veins show the greatest divergence as to their contents and value, no influence on their character can be attributed to the different formations. In general, the mines in this vicinity are characterized by comparatively low-grade bullion, about 750 fine, much sulphurets, and especially much arsenopyrite and zincblende. A strong system of sheeting is developed parallel to the first-mentioned system of veins; the flat, thin benches of granodiorite dipping west are particularly well exposed along the Banner Hill road near Little Deer Creek; the sheets, from 6 inches to 2 feet thick, though as a rule parallel, sometimes show slight divergences in strike and dip. Small quartz seams are sometimes seen on the joints. The Banner Hill group of veins are in the main parallel fissures with an easterly dip of about 45°; they are partly in the sedimentary area, partly in the granodiorite, without very marked differences in vein filling and value; as a rule they contain much silver, and also a considerable amount of sulphurets. A sheeting of the country rock is frequently noticeable, the sheets dipping either east or west.

The Caledonia vein.—This vein is traceable on the surface for several hundred feet on the slope north of Little Deer Creek. The strike is a trifle north of east, the dip nearly vertical. It is opened by several old shafts and a tunnel from Little Deer Creek, 1,200 feet long, but no work has been done in recent years. The vein is said to be very wide and to contain low-grade ore. All above the tunnel level is stoped out; the ore consists of massive quartz with abundant pyrite. A considerable quantity of water, tasting strongly of iron and depositing a brown ocher, issues from the tunnel.

The Kingsbury veins.—South of the Caledonia, on the north side of Little Deer Creek, are two or three strong parallel veins, situated on the Kingsbury location. They have been opened only by short tunnels and prospect shafts; the dip is about 80° N., and the width of the solid quartz is from 1 to 3 feet. The Alice Belle is possibly an eastern extension of these veins.

The Lincoln vein, just south of Little Deer Creek, is a parallel vein in which a little work has been done, and which in the mint report is credited with a small production for the years 1889 to 1891.

The St. Louis vein.—The remarkably strong and straight fissure of the St. Louis vein can be traced for about 7,000 feet from the western limit of the Banner Hill sheet, on McCormick's ground, up to a place where it disappears under the andesitic breccia. Its direction is east-northeast and the dip 70° to 80° to the north. The ore throughout is very low grade, and the developments on it are slight, mainly confined to a few tunnels. At the eastern end its decomposed croppings have been extensively sluiced; on a claim called the Santa Rosa a crosscut is now being driven to intersect the vein. The Alpine tunnel was driven on this vein a distance of 400 feet in 1893, starting from the east bank of Little Deer Creek. On the opposite or Canada Hill side, there is also a tunnel on it several hundred feet long and serving as drain tunnel for the Charonnat mine. The width of the vein is given as up to 12 feet, but this doubtless includes the altered country rock. In the Alpine tunnel good exposures were noted. For the first 150 feet the granodiorite is much decomposed; farther in the quartz vein is from 1 to 4 feet thick and charged with a small quantity of pyrite and zincblende; both walls are well defined and consist of somewhat decomposed granodiorite. A dike of extremely decomposed diorite-porphyrite (a lamprophyric dike rock; for description, see p. 47) 2 to 3 feet wide appears in the hanging wall, 300 feet in, and forms the sharply defined wall of the 2-foot vein of solid quartz. Near the breast a seam was observed, dipping west and parallel to the sheeting previously noted; it cut across the quartz vein and showed a horizontal striation. Toward the west the vein splits up into three or four parts, and is well exposed on R. Sharpe's and McCormick's ground, where the shallow covering of rich alluvium has been sluiced off.

The Glencoe-Gracie (*Orleans*) *vein.*—This vein, one of the longest in the district, being traceable for nearly 3 miles, has been known since the earliest times of mining in this vicinity, but can show no product commensurate with its size, although it has been worked at several places. The strike is remarkably constant, being a little north of west. The dip is equally so, being 70° to 80° S. The vein throughout is in slate, which near the granite contact becomes more crystalline and schistose, and it cuts distinctly the dip of the schistosity. It first appears on the Mayflower ground, where it is called the Alaska and is opened by small prospect shafts, showing some good quartz heavily charged with sulphurets. Continuing westward, it is known as the Glencoe on R. Sharpe's ground. Here it is developed by a 98-foot-deep shaft and a 500-foot drain tunnel, above which the ore is stoped out. At this pay shoot the vein is stated to be 4 feet thick, contains abundant sulphurets, and is of medium grade. Steps were taken to reopen this mine in 1894. The next claim westward is the Gracie; a 54-foot shaft on this property shows 1 to 2 feet of quartz in a fissured zone 6 to 7 feet wide.

The westerly claims on this vein are described on p. 193. Between the St. Louis and the Glencoe a perfect network of small veins exists, the more important of which are indicated on the map. South of the Glencoe are the Hickson veins, opened by small shafts and a short tunnel, and said to have yielded some rich ore. Mr. Sharpe states that there are three veins within 50 feet, the outer two dipping toward the one in the middle, which is perpendicular. The Enterprise contains low-grade ore, and has not been worked since 1859.

To the north of the Glencoe there is, among others, a series of very flat veins with a southerly dip of from 0° to 20°. It is possible that the different croppings may represent one and the same vein, continuous from McCormick's ground to the Mayflower at Canada Hill. On the east the flat vein was found by Mr. McCormick in sluicing and hydraulicking the shallow placers and decomposed rock on the slope on both sides of the Gracie vein. It is here in slate, narrow, but rich, and sometimes so flat as to be almost horizontal. In one place it even made a roll, so that part of it actually dipped north. It is stated to have joined the Gracie vein without cutting the latter. Another flat ledge is found in granodiorite on Sharpe's ground near the contact and to the east of the Banner Hill road, and, finally, similar veins are strongly developed on the Mayflower ground.

THE MAYFLOWER COMPLEX.

At least eight well-defined veins are found on the Mayflower property south of Canada Hill. The more important veins were located over twenty-five years ago, but until ten years ago had not been worked except superficially. A 4-stamp mill crushed rock from the Beckman vein in 1893, but in 1895 a new 20-stamp mill was erected. The developments in 1893 consisted of an incline and several tunnels on the Beckman and the Mayflower veins. The Beckman has been worked for 1,500 feet along the croppings and 300 feet along the dip, but the greatest perpendicular depth attained is only 75 feet. On the Grant a 300-foot incline has been sunk. The country rock throughout is a black, very imperfectly schistose argillite, grading into hornfels near the contact. Only the Grant vein cuts across the contact into the granodiorite. Strong jointing is shown at the Beckman incline, one system dipping 60° west, while the other dips 30° to the east.

The three perpendicular east-west veins, the Butterfly, North Star, and Big Blue, while strong and well defined, carry low-grade ore and have been but little exploited, and the same is true of the Floyd vein. The Grant vein is more productive and contains near the contact, as well as northward in the adjoining Canada Hill ground, some good pay shoots; 555 tons, averaging $19, were extracted from the Grant by the owners of the Canada Hill or Charonnat vein between 1879 and 1887. The vein is narrow and contains very much arsenopyrite, besides pyrite, zincblende, galena, and some coarse free gold.

The Beckman, with which the Mayflower vein found higher up on the hill may be identical, is the most important vein in the complex. It dips very gently south, being at times flat, or even rolling over with a northerly dip. The vein is seldom over 12 inches wide and the walls are very ill defined and irregular, the argillite being bleached and filled with calcite, pyrite, and arsenopyrite next to the vein. The ore consists of the usual massive quartz with an often considerable amount of zincblende, galena, arsenopyrite, and pyrite. The ore is often high grade, and the free gold unusually coarse, being frequently visible in small particles embedded in quartz, galena, or zincblende. The gold is worth $15 per ounce, or 750 fine.

Faults in the Mayflower complex.—The Butterfly, North Star, and Big Blue—that is, the perpendicular east-west veins—distinctly fault the

Floyd and the Mayflower. None of the intersections being visible at the time of my visit, I rely upon the statements of Mr. W. H. Martin, for many years owner and superintendent of the property. The relation of the east-west veins to the Beckman is shown by the diagram, fig. 13, indicating a relative downward movement of perhaps 20 feet of the sheets between the Big Blue and the North Star. A horizontal projection of the Floyd and the two faulting veins shows the relation indicated in fig. 14, the amount of the faults not exceeding 20 feet.

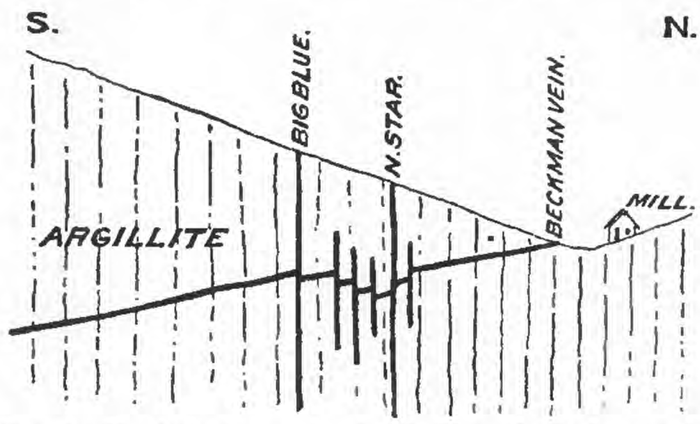

FIG. 13.—Vertical section, showing faults on the Beckman vein, Mayflower mine.

The Canada Hill (Charonnat) vein.—This vein was worked from 1854 to 1863, but the most extensive work on it was done between 1879 and 1887, in which period the mine produced 19,810 tons of ore, containing about $18 per ton; the exact percentage of sulphurets was 2.8, averaging $90 per ton. The ore yielded $14.80 per ton in amalgamated gold bullion, containing 73 per cent of gold and 27 per cent of silver, and $3.20 per ton in concentrated sulphurets, probably containing much silver. The Canada Hill incline is 1,300 feet deep on the vein and there are over 9,000 feet of drifts; the country rock is a normal granodiorite. The vein strikes north and south, bending to the northwest north of the shaft, and dips 15° to 20° W.; in places it is almost horizontal. It is 15 to 18 inches wide, frequently, however, closing down to a seam. The ore contains, like the Grant, besides free gold, much arsenopyrite, zincblende, galena, and pyrite, and is beautifully ribboned by alternating streaks of sulphurets. Near the cross veins this sulphureted ore is said to change to a more quartzose character, with occasional rich bunches at the intersection. An analysis of the ore showed the presence of tellurium (Mint Report, 1882).

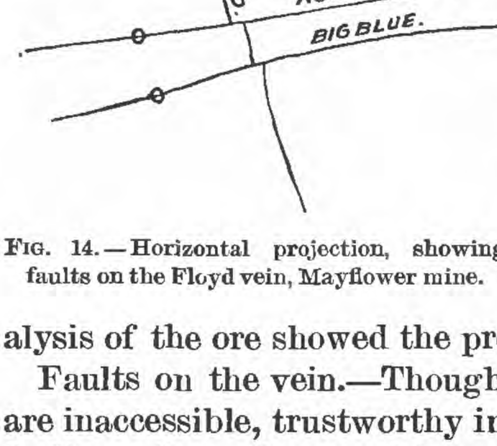

FIG. 14.—Horizontal projection, showing faults on the Floyd vein, Mayflower mine.

Faults on the vein.—Though at present the underground workings are inaccessible, trustworthy information in regard to the well-defined faults on this vein was obtained from Mr. Charonnat, and his information is verified by the underground maps and by inspection of the cross-seams on the surface. The Canada Hill is crossed by the heavy St. Louis vein, as well as by a great number of other fissures, rarely carrying quartz, striking a little north of east and perpendicular or dipping slightly north. All these throw the Canada Hill vein to the left, going north on the vein. The greatest fault is that produced by the St. Louis, which amounts to 150 feet on the surface and in the drain tunnel, measured in a horizontal direction, which corresponds to a vertical displacement of 45 feet. Between the St. Louis vein and the shaft there are at least two and probably more faults, throwing the Canada Hill an aggregate amount of about 150 feet in horizontal distance; the vein is often cut off as with a knife, as is shown by a portion of the map of the mine given in fig. 16. The rule for finding the faulted vein in the Canada Hill mine is, clearly, to drift in the hanging wall when going north on the vein.

The Grant vein, parallel to the Canada Hill, but dipping east, is apparently not faulted to any notable extent by these cross veins.

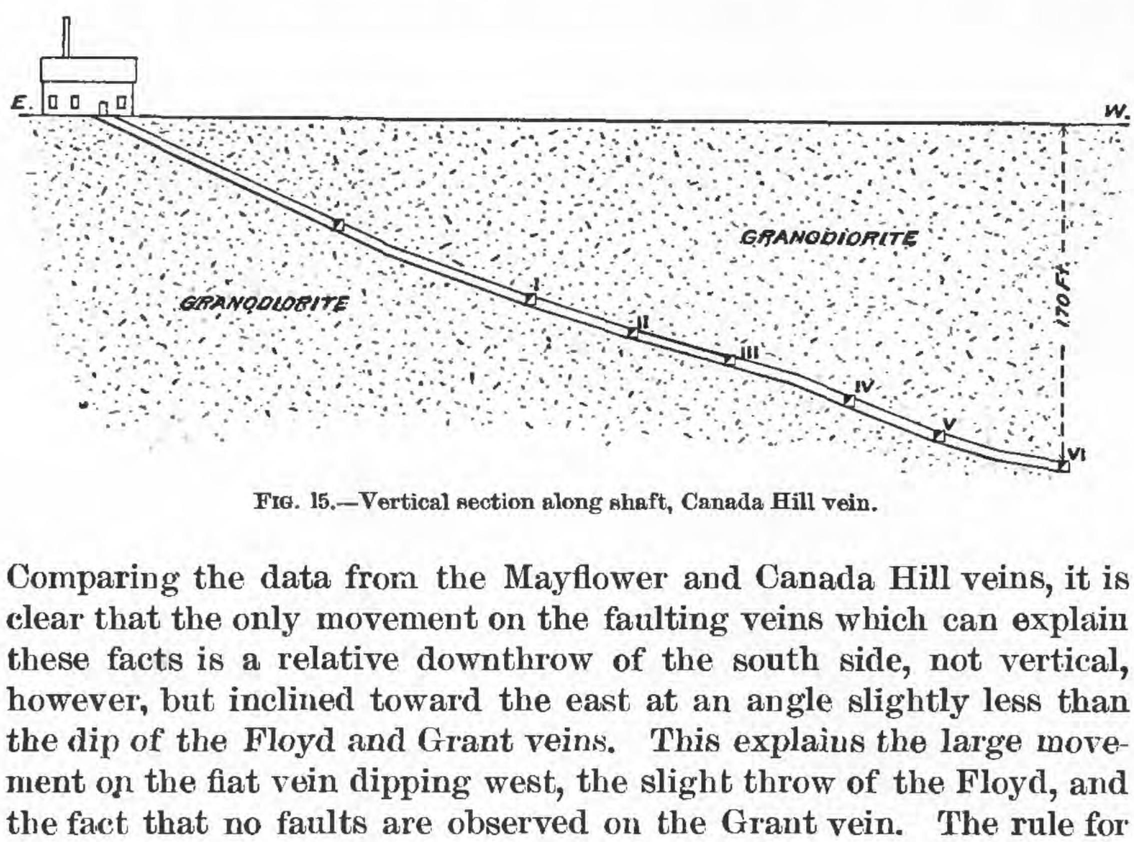

FIG. 15.—Vertical section along shaft, Canada Hill vein.

Comparing the data from the Mayflower and Canada Hill veins, it is clear that the only movement on the faulting veins which can explain these facts is a relative downthrow of the south side, not vertical, however, but inclined toward the east at an angle slightly less than the dip of the Floyd and Grant veins. This explains the large movement on the flat vein dipping west, the slight throw of the Floyd, and the fact that no faults are observed on the Grant vein. The rule for finding the faulted parts of the veins dipping east is thus to drift in the foot when going north on the vein. Many of the faulting fissures are vertical, so that no distinction can be drawn between normal and reversed faults. The St. Louis, however, dips about 85° N., and the fault produced by it is therefore a reversed or overthrust fault.

The Greenman vein, a short distance west of the Canada Hill, dips to the east and, according to Mr. R. Sharpe, intersects the latter without faulting or being faulted. Drusy quartz, galena, pyrite, arsenopyrite, blende, and molybdenite were noted on the dump.

The Wide West is a small vein parallel to the Canada Hill and cropping in Little Deer Creek. It is said to be 1 foot wide and to contain good quartz, but a heavy influx of water in the shaft stopped the developments.

The Union vein.—Located about a mile east of Canada Hill, on the north side of Little Deer Creek, this vein is the most westerly of the

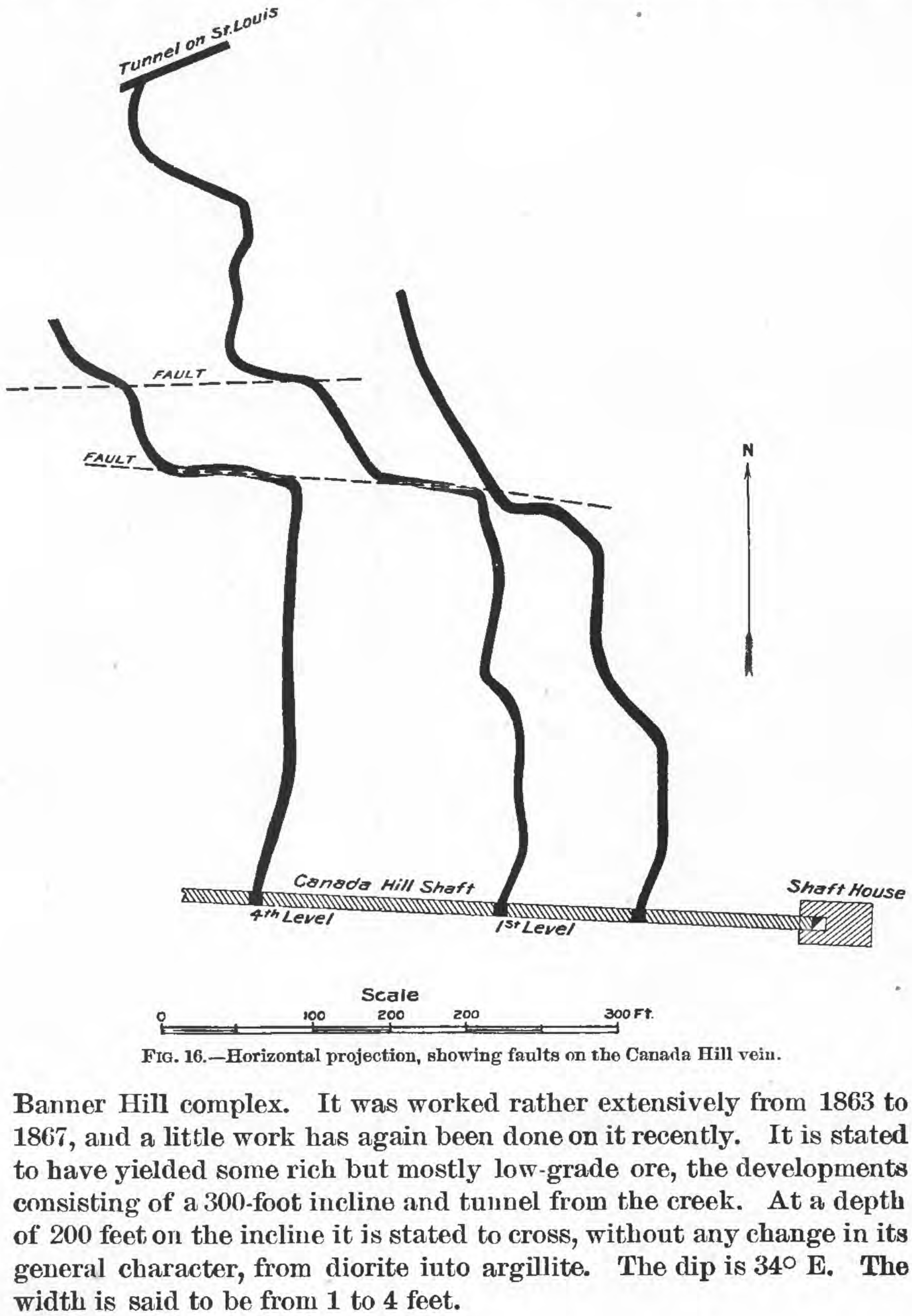

FIG. 16.—Horizontal projection, showing faults on the Canada Hill vein.

Banner Hill complex. It was worked rather extensively from 1863 to 1867, and a little work has again been done on it recently. It is stated to have yielded some rich but mostly low-grade ore, the developments consisting of a 300-foot incline and tunnel from the creek. At a depth of 200 feet on the incline it is stated to cross, without any change in its general character, from diorite iuto argillite. The dip is 34° E. The width is said to be from 1 to 4 feet.

The Banner vein.—Situated on the western slope of Banner Hill, this vein was located in 1860 and worked most actively during the latter part of the seventh and the beginning of the eighth decade, during which time it produced several hundred thousand dollars. During the year ending June 1, 1871, the mine yielded $135,180. In 1881 the work was resumed farther north on the vein, and the mint report of 1881 stated "the incline (north of the old shaft), now 280 feet deep, will be sunk to a depth of 800 feet before drifting for the old Banner shoot." The work was discontinued two years later, the shoot presumably being found less rich than expected. The old shaft is 670 feet deep on the incline. The vein, striking north-northeast and dipping 45° E., is inclosed in siliceous argillite, similar to that of the Federal Loan, and has a great tendency to split up in stringers, on account of the hard, splintery rock. The vein is said to average 4 feet. The ore contains a large percentage of sulphurets, and great difficulties were experienced in milling it. The tailings from the Banner mine were very rich, and are still being worked by arrastras and other appliances. The pay shoot was, in the upper levels, at least, extremely well defined, 300 to 400 feet wide, and dips N. 45° on the plane of the vein. In 1867 the ore was said to average $20 to $30 per ton, and contained considerable silver.

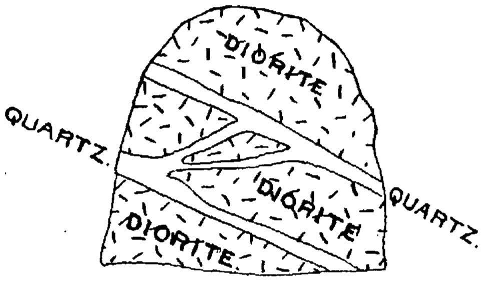

FIG. 17.—Woodville vein, North Banner mine.

The North Banner veins.—The Banner vein can be traced for about 1,500 feet to a point a little south of the diorite contact. North of the creek it is replaced by four veins, which are worked under the name of North Banner, and referred to, going from west toward east, as the Woodville, Dunnington, Tinny, and Reindeer veins. The first is the principal producer, being credited with $175,000 in the mint reports for 1889 to 1892. They are comprised within a distance of 450 feet, and the dip varies from 30° to 45° E. The Woodville is developed by a 1,000-foot-long drain tunnel, at the end of which there is an underground incline 500 feet long, following the ore shoot down. The mine is worked only on a small scale at present. The main Woodville tunnel starts in hard, dark argillite (contact metamorphosed), but strikes the diorite within 100 feet. The veins are entirely in diorite. Strong sheeting, dipping west, is developed at the mouth of the Woodville tunnel, while an equally strong sheeting, dipping east, shows in the vicinity of the Tinny vein. The Woodville vein shows a decided bend to the west in its northern end. The veins are very regular, from 1 to 2 feet wide, and are filled with the usual massive quartz and sulphurets. The country rock is not extensively altered. The veins are comparatively regular, and little of that splintering

VIEW OF SUGAR LOAF AND CEMENT HILL FROM NEVADA CITY.

noticeable in the argillite veins is to be observed. The sketch (fig. 17) shows the Woodville at a place where it has split into two veins. The ore sometimes contains as high as 5 per cent of sulphurets,[1] consisting of pyrites, galena, molybdenite, and tetrahedite,[1] and is characterized by a remarkably high percentage of silver. The reported product of 1890 was $48,100 in gold and $2,300 in silver, or 2,450 ounces gold and 1,780 ounces silver. The ore yields $10 per ton by amalgamation, and almost an equal amount in sulphurets, the latter containing about $160 per ton, one-half to two-thirds in value being gold, the remainder silver. The pay shoot on the Woodville, though somewhat irregular, has an extent of 500 feet, and dips to the north on the plane of the vein.

There are several claims to the east of the North Banner, located on parallel and similar veins, but very little work has been done on them. Near the top of Banner Hill, in brecciated argillite, are the Tiptop and Peerless veins, striking N. 30° W. and dipping 60° E. The developments consist only of small inclines and tunnels. Some rich specimens were extracted from the decomposed quartz of the Peerless in 1893. In the continuation of these veins southward is the old British America, said to have yielded some low-grade ore. The whole west side of Banner Hill is apparently traversed by a system of parallel fractures dipping east.

The Grand Central vein lies in the continuation of this belt just outside of the limits of the map, 3,300 feet from the southeastern corner, the country rock being black slate. This vein was worked for silver long ago, but without much success, and pyrargyrite, in fact, occurs on it. In the same vicinity are several other quartz veins, from which gold quartz is said to have been extracted to the value of several thousand dollars.[2]

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[1] Eighth Rept. State Mineralogist, p. 421.

[2] Bean's Directory.

CHAPTER XV.

DETAILED DESCRIPTIONS—(CONTINUED).

NEVADA CITY DISTRICT.

The productive veins in this district are, on the whole, concentrated in the vicinity of the contact of the granodiorite with the metamorphic slate, though only a few of them actually occur on the contact. There are many strong and persistent veins among them, frequently wide and heavily charged with sulphurets. On the whole they contain less silver than the Banner Hill and Willow Valley veins, but more than the Grass Valley veins. The principal veins belong to two systems—(1) the west-northwest to east-southeast veins, with a steep southerly or northerly dip, and (2) the north-to-south veins with a medium easterly dip. The former system is represented by the strong and continuous Orleans mine, and in the northern part of the sheet by the Sargent & Jacobs, on which but little work has been done. The second, to which most of the productive mines belong, consists of a number of strong veins, apparently radiating from a point in the vicinity of Town Talk in directions ranging from north-northwest to north-northeast. The Providence-Champion complex embraces the largest veins in the whole region here discussed, and the considerable faulting which has taken place along it renders it of especial interest. Contrasting with these wide veins and broad faulted zones are the narrow and clear-cut fissures of the Mountaineer and the veins in Nevada City. The intimate connection of the two principal systems referred to above is emphasized by the sudden bend of the Ural vein, changing from a north-northwest to a west-northwest direction, and by the less emphasized bend of the Merrifield vein. North-south veins dipping west are rare and are only represented by the Sneath & Clay and the Mohawk. The extensive seam belt west of the Providence-Champion system forms an especially interesting feature.

A few scattered veins occur in the diorite area about Stocking and Pleasant flats. On one of them, just north of Stocking Flat, a small pay shoot, containing about $1,000, is said to have been found. The veins occur in granodiorite, diorite, sedimentary siliceous slates, porphyrite, and amphibolite, without great differences in the composition of the filling. None have, however, been found in the serpentine. The veins of the Providence-Champion system carry the largest amount of sulphurets, but all of the veins contain in the pay shoots a relatively abundant quantity of free gold.

The sheeting of the country rock is not prominent, except in the immediate vicinity of some of the larger veins and along the seam belt. At the latter place it is very well defined, and the joints dip to the west. Outside of the limits of the sheet to the northwest of Coan's mine there is a series of veins, not continuous, however, and not located on any contact. Among these are the Oro Fino, Yellow Diamond, Etna, and others.

The veins of Gold Flat will be described first, then those of Nevada City, lastly the Providence-Champion system and the seam belt.

The Orleans vein.—Forming the continuation of the Glencoe (Gracie) vein in the Banner Hill district, the Orleans can be traced for 1½ miles west of the eastern boundary of the Nevada City sheet. The vein has been a very small producer, no important pay shoots having thus far been found. The developments are also slight. The Orleans tunnel is driven on it a short distance east of where the vein crosses the railroad, and the Orleans shaft, 200 feet deep, is sunk 900 feet east of the lower Grass Valley road. At the upper Grass Valley road the Fortuna mine is located, with a shaft 250 feet deep. The vein shows here several feet of low-grade quartz containing considerable sulphurets. The Live Yankee is a stringer south of the Fortuna, and probably connected with the main vein. No work was done on this property in 1893. Near its western end the vein has been opened by several shafts south of the Crosby shaft on the Providence vein, and a crosscut from the first level of the latter found the Fortuna 500 feet southward. The vein lies nearly the entire distance in siliceous clay-slate, grading over into micaceous schists near the granodiorite contact. The strike is about N. 70° W. and the dip constant 70° to 80° S. Only at the extreme western end does it enter the porphyrite area. It is not, as is frequently asserted, a contact vein. With the present developments the opportunities to study this interesting vein are not good. More extensive prospecting might well develop good ore shoots on it.

The Manhattan is a short vein parallel to the Orleans and near the eastern edge of the area shown on the Nevada City sheet. A statement in Raymond's Report, 1871, page 45, gives the thickness of the vein as 2 feet, and mentions that it showed plentifully in gold and sulphurets. It has not been worked in recent years.

The Morning Star and the Eureka veins.—North of the Orleans vein and just east of the railroad the contact of granodiorite and slate is cut by a number of short veins, striking north and dipping east from 45° to 70°. On the Eureka some work was done many years ago, and a great number of small vertical shafts were sunk to open the vein. The Morning Star was being opened in 1893 on a small scale by an inclined shaft in the slate, and some good ore is said to have been found.

The Sneath & Clay and the Mohawk veins.—These two short veins in granodiorite are characterized by a westerly dip, unusual in this vicinity. The Sneath & Clay is located a mile south of Nevada City, just east of the first railroad curve. Discovered in 1862 by means of the rich quartz specimen found in the placers just below it, it was worked quite extensively up to 1865, producing about $200,000 and yielding ore from $32 to $180 per ton. From 1865 to 1867 it was also worked, yielding a fair profit, the rock at times containing $40 per ton. Soon afterward it was shut down, and has remained so since then. The vein has a flat westerly dip of 23°, and the incline is run 400 feet down along the ledge. The vein is irregular in size, but averages something over a foot in width. The pay shoots are evidently small, but rich; the gold, 823 fine. According to T. H. Rolfe, in Bean's Directory (p. 56), the pay shoot in the upper levels is 150 feet in length, contracting below to 100 feet.

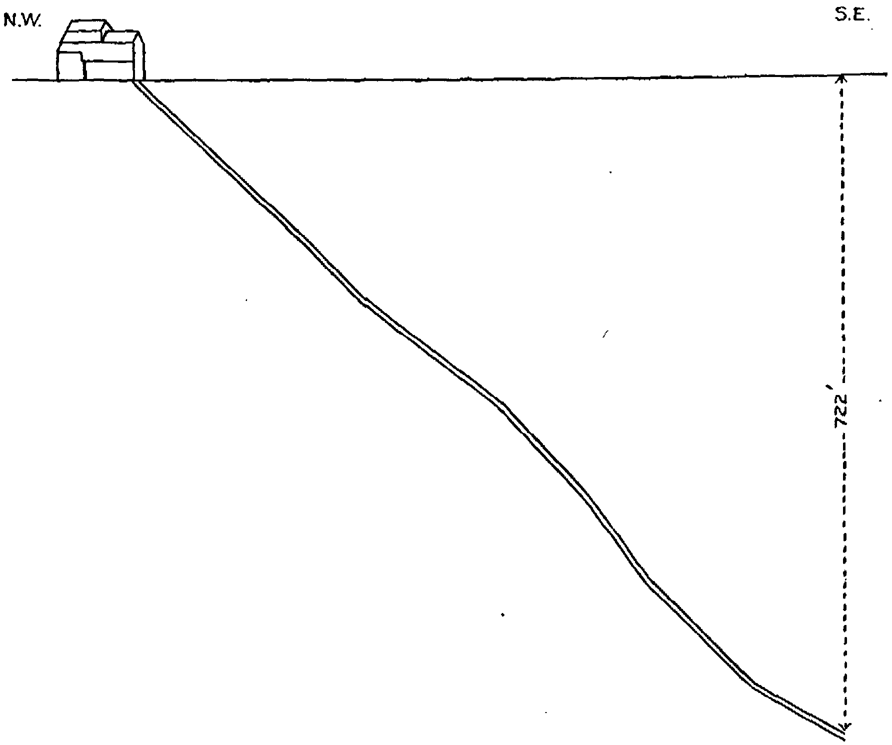

FIG. 18.—Vertical section along shaft, Pittsburg vein.

The Mohawk vein, located half a mile southwest of the Sneath & Clay, was also worked during the sixth decade and opened by a vertical shaft 118 feet deep. At least 500 tons of ore were taken out, averaging $34 per ton. The vein appears to contain rich pockets of free gold, in which many fine specimens have been found. These notes are chiefly from Bean's Directory.

The Pittsburg (Wigham) vein.—This vein was discovered in 1851 and worked at intervals with indifferent success till 1862; in this year it produced $85,000, with an average of $23 per ton. From 1866 to 1872 the mine produced largely, $102,000 being the yield of 1866,[1] the ore averaging $60, and $150,000 the yield of the year ending June, 1870. In the last twenty years the mine has been worked intermittently; in 1893 exploitation was confined to the fourth and fifth levels south of the shaft. A good report on the property by Mr. J. D. Hague is found in Raymond's fourth annual report. The depth of the main shaft was at that time (1872) 783 feet on the incline.

Present developments consist of an incline shaft with a dip of 43° and a length of 1,000 feet, and an old incline shaft 500 feet long and 400 feet to the south of the main shaft. The drifts of the upper eight levels are extended from 400 to 600 feet north and south of the shaft; from the lowest two levels the drifts have been run for only a short distance. There is a 10-stamp mill on the property.

The country rock is a dark-green, hard diabase, the augite largely converted into hornblende. The croppings of the vein are obscured by the decomposed surface rock; the strike of the vein averages N. 45° E., and the dip 43° SE. with many minor variations (fig. 18). The walls are well defined, the foot wall especially so; the vein is a clean, hard, and compact seam of quartz, averaging in thickness from 12 to 15 inches. Generally the quartz seam fills the entire space between the walls, but in the places where the walls are farther apart the mass between them consists of crushed country rock impregnated with pyrite and calcite, through which two or three veins of massive quartz are distributed. Such an occurrence is shown by fig. 19, drawn by Mr. E. C. Uren, in the now inaccessible ninth level. The pay is in the quartz, the crushed and altered country rock being very poor; "the free gold everywhere present in the quartz is sometimes, though not always, visible. The sulphurets with which much of the gold is associated are generally present, sometimes sparsely distributed in bunches and specks and in other places forming solid seams several inches in thickness" (Hague). Pyrite is plentiful; there is also some galena, but only very little blende and chalcopyrite. Arsenopyrite occurs occasionally. The sulphurets are rich, ranging from $100 to $200, and the ore is in general high-grade, averaging $36, the bullion being 806 fine. The wall rock is remarkably hard and fresh, and frequently lies up close to the vein; the altered country rock, replaced by pyrite, sericite, and carbonate, is confined to the crushed rock between the walls. A remarkable fact is that all quartz in the vein is good ore and goes to the mill. "The pinches or contractions in the vein in the stoped portions are seldom more than a few feet in horizontal measurement, while the expanded portions of the continuous quartz are very much greater, in one case over 200 feet" (Hague). The stopes are very extensive, those on the third level reaching 400 feet north of the shaft and 700 feet southward. While the developments on the lowest levels are small, it

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[1] Bean's Directory.

is clear that the pay shoot in this part of the mine has contracted and split in two, one on each side of the shaft. As a whole, the wide shoot may be said to dip to the northeast on the plane of the vein.

The developments to the southwest have generally stopped when a series of fissures faulting the vein was encountered, but, as shown by the work of the last few years on the fifth level, good ore occurs in and beyond the faults. The faulting fissures strike east-west, are nearly

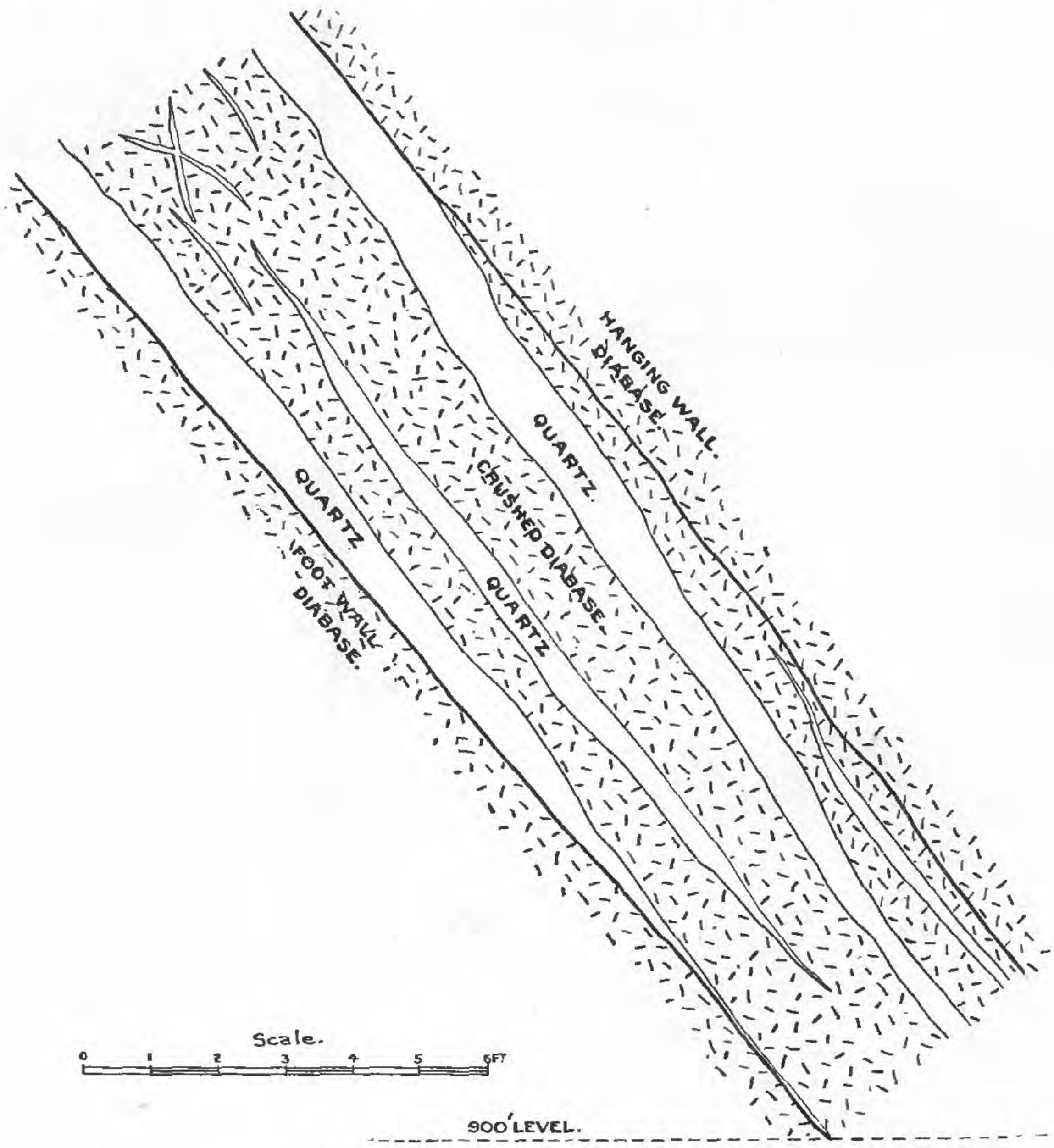


FIG. 19.—Section of Pittsburg vein, ninth level.

perpendicular, and contain no quartz; at least three of them have been recognized, and Hague mentions that the vein south of the old shaft down to the fourth level has been traced through three of these faults and appears to be somewhat enriched by them. Below the fifth level the vein has not yet been followed through the faults. The same fissures are found to fault the adjoining Gold Flat vein. The throw of the faults measured along the drifts does not exceed 40 feet, the north side generally showing a relative downthrow; that is, the vein will be found by drifting to the left along the fault. The faulting plane is sometimes seen to curve around slightly when the vein is reached, although on the whole following its course without change. In one instance on the third level the vein is bent over, following the fault for a few feet.

The Gold Flat or Potosi vein.—Located 1,000 feet west of the Pittsburg, this vein has been developed at the southern end by the Potosi shaft, 400 feet deep along the incline, sunk about 1865, and 750 feet north of this by the Gold Flat shaft, 300 feet deep, on which work was being prosecuted in 1893 and 1894. There is a 10-stamp mill on the property. The vein is inclosed in hard uralitized diabase or porphyritic diabase, strikes a little east of north, and dips east at an average angle of 38°. It is somewhat irregular in direction and dip, as well as in thickness, the latter ranging from a mere seam up to 18 inches. The sulphurets are not very abundant and consist chiefly of iron pyrites and a little galena; the gold is 816 fine. There are two ore shoots on the vein; one, about 75 feet wide, begins at the Gold Flat shaft and dips south on the plane of the vein, contrary to the general rule, while the other begins at the Potosi shaft, is 425 feet wide, and dips to the north. It is expected that the pay shoots will unite in depth. In 1893 ore was extracted from the shoot in the vicinity of the Potosi shaft, reached by a drift on the 212-foot level of the Gold Flat shaft. At least two barren fissures (crossings) fault the vein, one on each side of the Potosi shaft. They strike east-west, and are perpendicular or incline slightly north or south. In the more southerly of the two faults the vein was seen to be cut off as with a knife by the smooth, glistening seam of the faulting fissure. The throw, measured along the drift, is from 10 to 20 feet, and to straighten the fault it is necessary to drift to the left along the crossing; this corresponds to a downthrow of the northern blocks.

The Mohigan vein.—A few hundred feet northwest of the Gold Flat, and between that mine and the Thomas, is the east-west vein of the above name. It dips 38° S., and would seem to correspond to the flat east-west veins on the Mayflower, Sharpe, and McCormick properties. The Mohigan shows an average width of 1 foot and has been worked for a distance of 800 feet along the cropping, but to no great depth, the shaft being 150 feet deep. The ore is said to have averaged $30 per ton.

The Merrimac vein.—Situated about 2 miles south of Nevada City, on the south slope of the Town Talk Ridge, this short vein shows the somewhat unusual dip of 42° N. It is opened by a shaft 385 feet deep on the incline. The drifts extend chiefly eastward from 100 to 300 feet. The vein lies in the black, tuffaceous Mariposa slates, and cuts their strike and dip. It is said to be from 18 inches to 3 feet wide and to contain a pay shoot 300 feet long. The ore is banded quartz, containing galena, besides free gold, 817 fine. These notes are from the Eleventh Annual Report of the State Mineralogist, the mine not being worked during 1893 and 1894. The small hydraulic pit near the mine was excavated to wash the decomposed croppings of this vein below the andesite.

The Thomas and Grant veins.—It has already been stated that the principal veins crossing Deer Creek and dipping east converge toward a center in the vicinity of Town Talk. All of them appear, however, to die out before reaching the Fortuna cross vein, and south of that there are only two veins which represent the Deer Creek vein system. On one of them, the Thomas vein, striking north-northeast and dipping 45° E., perpendicular and inclined shafts have been sunk to a depth of 800 feet on the incline. The ore bodies are said to be very irregular, ranging from a few feet to 150 feet in width. The ore is heavily charged with sulphurets and frequently very rich. No work has been done on the property for a long time.

The Grant vein, 1,200 feet north of Town Talk, has been opened by a tunnel. In its southern part, called El Capitan, considerable capital was expended about 1880, without returns. This vein might, from its position, be considered as the southern continuation of the Merrifield.

The Eagle vein.—This is a short vein cropping near the cemetery south of Deer Creek, half a mile east of the bridge. It is opened by a 500-foot-long tunnel from Deer Creek, is said to be 8 inches wide, and contains some high-grade ore. In 1881 the vein was worked to some extent.

Parallel to this are the three larger veins described immediately below. They may be characterized as sharp, clear-cut, single fissures, narrow but frequently rich in free gold, and incased in very hard granodiorite, and may be referred to as the city veins, because outcropping within the limits of the city.

The Nevada County (Italian) vein.—This vein, cropping at several places on Piety Hill, crosses Deer Creek at the suspension bridge and, continuing under the center of the city, splits into two branches. It was discovered in 1866, but has not been worked for many years past. The main shaft near the bridge is 230 feet deep on the incline, but no levels are turned below 200 feet. The first level extends 700 feet north and 50 feet south; the second level, 200 feet north and 500 south. There is a main shoot at the shaft, and two smaller shoots to the north and south of it, all dipping to the north. The dip is 50° E.; the width variable, generally narrow, but occasionally up to 2 feet. The ore runs from $20 to $40. A 3-foot-wide barren and perpendicular cross vein faulted the Nevada County vein about 600 feet north of the shaft, the throw being 6 feet. At this crossing the ore was very rich, reaching $100 per ton.

The Stiles (Midnight) vein.—The southern part of this vein, known as the Half-mile House ledge, has been prospected all along its course and opened by an incline shaft. North of Deer Creek it has been opened by a tunnel from Deer Creek, and some good ore is said to have been found.

THE GOLD TUNNEL VEIN.

This prominent and rich vein has been worked by the Reward, California, Gold Tunnel, and Pennsylvania mines, along a distance of 7,000 feet.

The Reward mine is located at the southern end of the vein, where it is split up into two branches about 180 feet apart. The Reward shaft, located on the eastern vein, is 200 feet deep on the incline and dips 33° E. A pay shoot on this vein was stoped in 1894. The vein is very regular and of an average thickness of 1 foot of solid quartz. At the depth attained the granodiorite is very soft and decomposed, and most of the sulphurets are oxidized. As a preliminary to sinking, a drain tunnel is being driven from Deer Creek.

The California mine, north of the Reward and on the south side of Deer Creek, was located in 1857 and worked in a desultory manner until 1866, when new machinery was erected; the mine shut down again, however, in 1868. It was exploited again about 1875, for which year it is credited in Raymond's Report with a production of $90,000; for many years past it has been idle. The incline is 540 feet deep along a dip of 37½°, and has three levels turned below the drain, which are from 200 to 500 feet long. The vein is said to vary from 1 inch to 4 feet in width, the average probably being 1 foot; the ore is reported to contain about $19 per ton and 3 per cent sulphurets.

The Gold Tunnel, on the north side of Deer Creek, has the distinction of being the oldest mine in Nevada City, being located in 1850. From 1852 to 1855 it is known to have yielded $300,000, averaging $50 per ton; from 1855 to 1863 it was worked continuously, with unknown output. In 1868 the ore above the tunnel level was not yet exhausted. It was worked more or less continuously until a short time after 1875, since which time it has been idle. The vein is opened by a long drain tunnel from Deer Creek, connecting with the old incline halfway up the hill and with the new shaft on top of the hill. The latter is sunk 360 feet on the incline below the tunnel, two levels being turned, the lowest 250 feet below the drain. There appear to be several pay shoots on the vein. The width of the vein, while variable, is said to average 1 foot 2 inches, and the ore contains 2 per cent sulphurets.

North of the Gold Tunnel lies the *Eddy claim*, reported to have produced some ore, and the *Pennsylvania*. The latter mine, which has not been worked for many years, lies northwest of Nevada City, and its shaft is started in the Neocene gravels covering the vein. According to a report in the possession of the Citizens' Bank, the shaft is 500 feet deep on the incline, with drifts 400 to 500 feet long on each side. The dip is 45°, with good foot wall; the size of the vein, 18 to 24 inches, mostly ribbon rock. About 15,000 tons have been extracted, yielding $20 in free gold and 8 per cent sulphurets, the latter containing $100 per ton.

THE MOUNTAINEER VEIN.

Extending from Deer Creek for at least 5,000 feet northward, this vein is, in the character of its fissure, related to the city veins, though its ore is more like that of the Providence system. It has been worked extensively for the last fifteen years, and is estimated to have produced $1,000,000 in this time. The principal developments are in the southern part of the vein, but it has been traced over the exposed bed rock of the hydraulic diggings, where it shows as a small seam, and bends to the north-northwest, one branch extending north-northeast. Some ore assaying $80 was extracted near the large pond in the diggings, and the same vein is shown 4 to 5 inches thick in the Grover and Knickerbocker tunnels.

The Mountaineer mine is opened by a tunnel from the north side of Deer Creek. One thousand feet from the mouth a shaft is sunk 850 feet deep on the incline. Seven levels are turned, with a maximum extension of 1,100 feet to the north and 650 feet to the south. A 20-stamp mill is erected on the property. The vein is clear-cut and well defined, with a direction of N. 18° E., and dips 37½° E. on the tunnel level. It is inclosed in very hard granodiorite, the fresh rock generally lying close up to the vein. The width averages about 1 foot, but is very variable; when it occasionally swells to 3 or 4 feet the ore usually becomes poor. There is no sheeting of the rock adjoining the vein, but the quartz forming the filling is frequently ribboned by sheeting and crushing; much pyrite, often also gold, is found on the sheeted faces. The sheets of quartz, 1 inch or less thick, often show pronounced striation, which is perpendicular to the strike, or dips slightly northward. The quartz contains, besides free gold, much sulphurets, the average being 3 or 4 per cent, consisting chiefly of pyrite, with much greenish-black blende and some chalcopyrite and galena. The sulphurets are rich, containing from $100 to $200 per ton. No arsenopyrite was observed. The ore is characterized by a considerable percentage of silver, and is said to average $15, the product of the mine being as follows:

Year.	Gold.	Silver.
	Ounces.	*Ounces.*
1890	4,262	2,341
1891	3,507	2,260
1892	3,552	2,000

The principal pay shoot begins at the reservoir on top of the hill and pitches a little north on the plane of the vein. On the fourth level the vein had shut down to a mere seam where the pay shoot should be, but opened up rich again on the next level below. Beyond this shoot the vein forks and has not been explored. The third, fourth, and fifth levels extend 200 feet south of Deer Creek. In the hanging wall, 170 feet from the main fissure, is found a heavy but mostly barren vein called the Black Prince, connected with the Mountaineer by a cross fissure.

Three cross fissures, striking northeast and dipping 60° N., cut the vein in the vicinity of the shaft on the tunnel level. They do not carry much quartz, and are stated to have faulted the vein 1 or 2 feet in some places. The massive quartz, without sulphurets, between the pay shoots averages $1.50 or $2 per ton.

THE MERRIFIELD VEIN.

The Merrifield vein is probably the longest one in the district, and forms, with the adjoining Ural vein, one of the most important vein systems of the district. The Providence, Merrifield, Spanish, and Mount Auburn mines are located on it, and there can be hardly any doubt that it is the same Merrifield vein which emerges from the volcanic capping on the north side of Cement Hill (northwest corner of map) and continues down to Hoyts Crossing. In such case the total length of the vein would be over 4 miles. The principal developments are on both sides of Deer Creek.

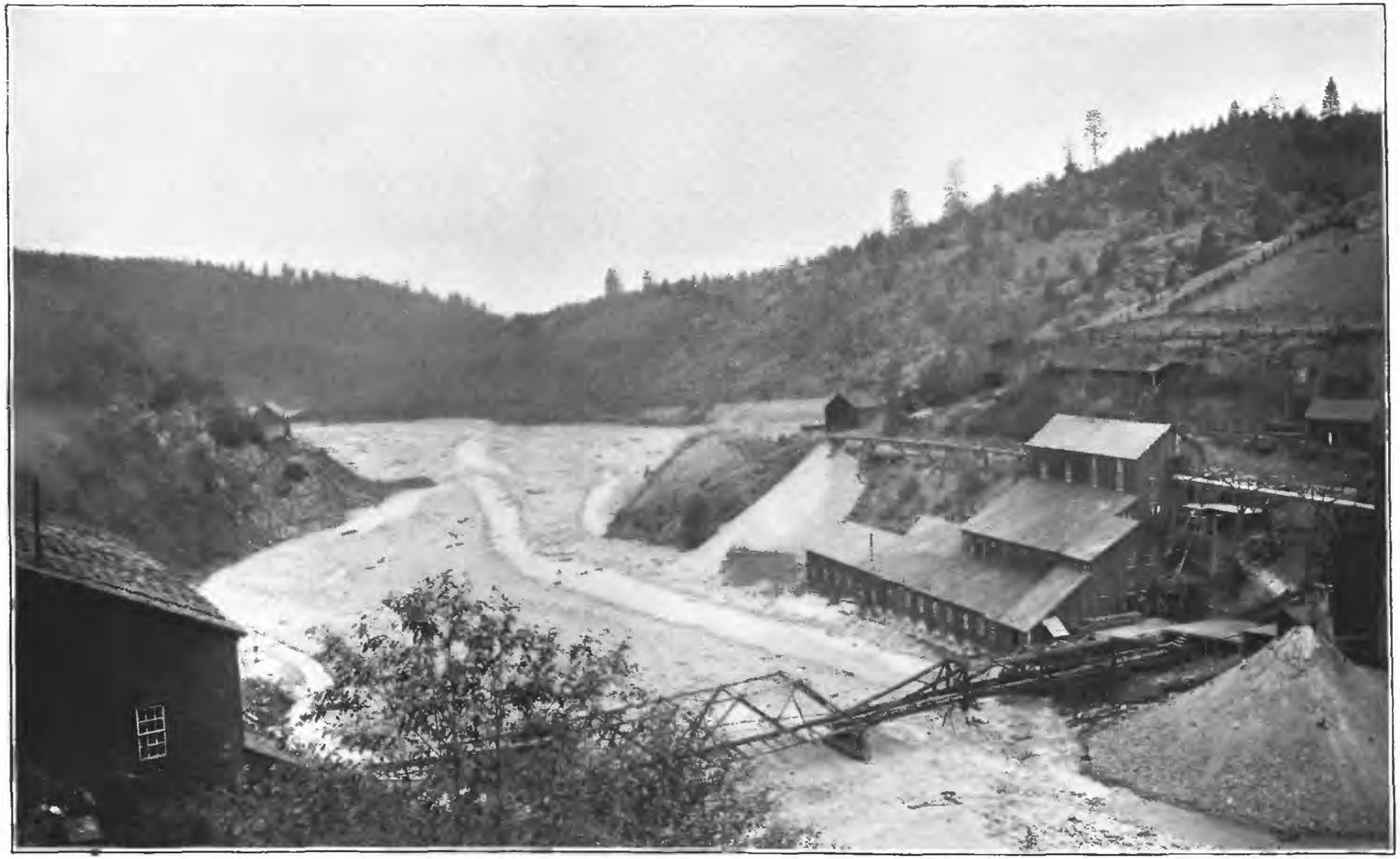
The Providence mine, on the south side of Deer Creek, was located early and worked on a small scale between 1861 and 1867. Considerable difficulty was experienced in treating the highly sulphureted ore, Knox pans being used to extract the gold from the concentrates. The exploitation of this and adjoining veins on a large and profitable scale really dates from the time of the introduction of the chlorination process. Since 1870, however, the mine has been worked almost continuously, with a short interruption about 1888, and with gratifying success. In the last years considerable ore has also been extracted by the Providence mine from the adjoining Ural vein. The mine is equipped with a 40-stamp mill and chlorination works. The total output of the Providence mine, or, indeed, of any of the mines on the Merrifield vein, is not accurately known. The Nevada County Mining Review estimates that the Providence has yielded $5,000,000 since its discovery, which figure, however, seems too large. In the mint reports of 1890 the mine is credited with $59,000, but the average output since then has doubtless been considerably larger.

The present developments consist of a shaft 1,800 feet on the incline and drifts on the vein aggregating several miles. The mine has been opened underground to south of the Crosby shaft, as illustrated on Pl. XXI. This plan is not intended to represent the complete workings, but only so much as may be necessary to an understanding of the important geological features involved.

The Merrifield vein is notable for its great width, and particularly for the great width of crushed material accompanying it. In fact, in this regard the Ural and the Merrifield stand alone in the districts; everything points to most intense dynamic action along these lines.

To the north of the Providence mine the Merrifield vein lies entirely in granodiorite; at that mine it cuts the slate contact obliquely at a slight angle, evidently following the latter on the surface for a few hundred feet, though the exposures are not quite decisive on account of surface decomposition. The relations of the slate and the granodiorite are particularly interesting in the Providence mine. The lower workings are all in granodiorite. In the drain tunnel, however, about 800 feet from the entrance, the vein encounters the contact and follows it as far as the drain is accessible at present. Both the hanging wall and the foot wall are very much crushed and decomposed, but enough is visible to justify the assertion that the vein follows the contact. The workings below the tunnel are not now accessible, but it is well known that the vein for a considerable distance below it followed the contact. A part of the data represented on the map are furnished by Mr. Thomas, for a long time the superintendent of the mine and probably better acquainted with the old works than anybody else. Now, as far as is known, the veins of the district exhibit the most marked indifference as to crossing or following any contacts; it is further known, from examinations covering a large area in the Sierra Nevada, that the contacts of the granitic rock with the slates either run wholly irregularly or—and this very frequently—are approximately vertical. It is very improbable that the contact should have happened to follow a plane which subsequent forces caused to be a fault plane. Taken in connection with the indications of intense crushing along the vein, the only rational explanation is that an overthrust fault has taken place with a relative upward movement along the hanging wall, amounting to about 1,000 feet measured along the dip of the vein. Indeed, if we assume an approximately vertical contact and a line of fissure crossing it at a slight angle, an upward movement of the hanging wall will place a part of the vein on the contact, producing a contact area extremely similar with that shown by the workings of the mine.

The vein strikes about north-south and dips 35° E. on an average, different parts dipping from 29° to 45°. Between the fresh unaltered walls there may sometimes be as much as 20 feet, or even more, of rock more or less crushed and divided by numerous fissures parallel to the vein. As a rule this "formation" is from 6 to 10 feet wide, though sometimes the fresh unaltered rock may be seen close to the vein. The quartz vein proper usually ranges from 6 inches to 4 feet in width, in isolated places reaching 10 feet. This solid, hard, milk-white quartz, not mixed with country rock, constitutes the ore. It contains much sulphurets in ribboned arrangement, partly due to primary deposition, partly to subsequent shearing. Where the width of quartz is extreme the ore is usually poor; for instance, on the 1,250-foot level next to the shaft. It must not be imagined that the ore follows a well-defined plane within the crushed and fissured zone. On the contrary, the quartz vein thins out in one plane only to appear in another, or there may be two or three



VIEW OF CHAMPION AND HOME MINES FROM PROVIDENCE MINE, LOOKING DOWN DEER CREEK.

more or less nearly parallel veins within the zone. The crushed granodiorite is seen in all stages of the process, from a mere softening down to a point where the rock is converted to a grayish-green schist with smooth, curved cleavage faces, and all its constituents flattened and squeezed. The slate, whenever present along the vein, has suffered in a similar manner, and there may sometimes be considerable difficulty in determining whether a given specimen is crushed slate or granodiorite. Analyses of these rocks are given on page 149. The crushed rock next to the vein contains much calcite by replacement and as small seams; considerable pyrite is also usually present. This altered and partly replaced wall rock carries a little gold, sometimes as high as $2 to $3 per ton.

The quartz contains, on an average, 6 or 7 per cent of sulphurets, consisting chiefly of pyrite, chalcopyrite, zincblende, galena, and a very little arsenopyrite. The free gold is very rarely visible. The distribution of the sulphurets is somewhat irregular, and on the whole there is less of them than in the Ural vein. Tellurides, while occurring on the Ural vein, are not definitely known from this vein. Molybdenite occurs rather frequently, and sometimes in large bunches, though usually not closely associated with the other sulphurets.

The concentrated sulphurets are said to assay from $80 to $225 per ton,[1] averaging $130, and contain considerably more silver than gold by weight, the relation being 3.5 ounces of silver to 1 ounce of gold. The gold is rarely visible to the naked eye. In 1890, according to the mint report, the mine produced 2,800 ounces of gold and 2,326 ounces of silver, or approximately equal quantities by weight.

The pay shoots on the Providence-Merrifield vein are rather irregular, size and value of vein often changing, but on the whole it may be said that the most important shoot follows the remarkable split of the vein shown in the plate, and dips to the north about 70°. The width of the fissured zone renders frequent cross cutting necessary.

The Merrifield mine, now owned by the Champion Company, is opened on the northward continuation of the Merrifield vein. According to Bean's Directory, this mine, formerly called the Soggs or Nevada Company, worked nearly continuously from 1857 to 1867, the yield ranging from $40,000 to $70,000 per year. In 1866, 5,000 tons were produced, yielding $42,000 in the mill and $8,000 in sulphurets. The mine was at that time developed by three tunnels, from 2,500 to 1,800 feet long. Between 1880 and 1884 work was resumed, with varying success. A shaft 900 feet deep was sunk opposite the Providence, and the drifts were said to aggregate 8,000 feet. The daily output of ore in 1882 is said to have been 55 tons. Since 1884 but little has been done, and during this examination the old works were not accessible. Recently it has been stated that the intention is to reopen the mine. From information available it is clear that the vein and the filling are entirely

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[1] Sixth Ann. Rept. State Mineralogist.

similar to those of the Providence mine. The vein and vein matter are wide, from 3 feet to 16 feet, and average 5 feet. Amount of sulphurets, 6 per cent. From the account it is plain that large ore shoots have been found in the mine, and it would be strange, considering the general character of the vein, if these shoots did not continue in depth. North of the Merrifield mine the vein of the same name is barren for some distance, though easily traceable on the surface.

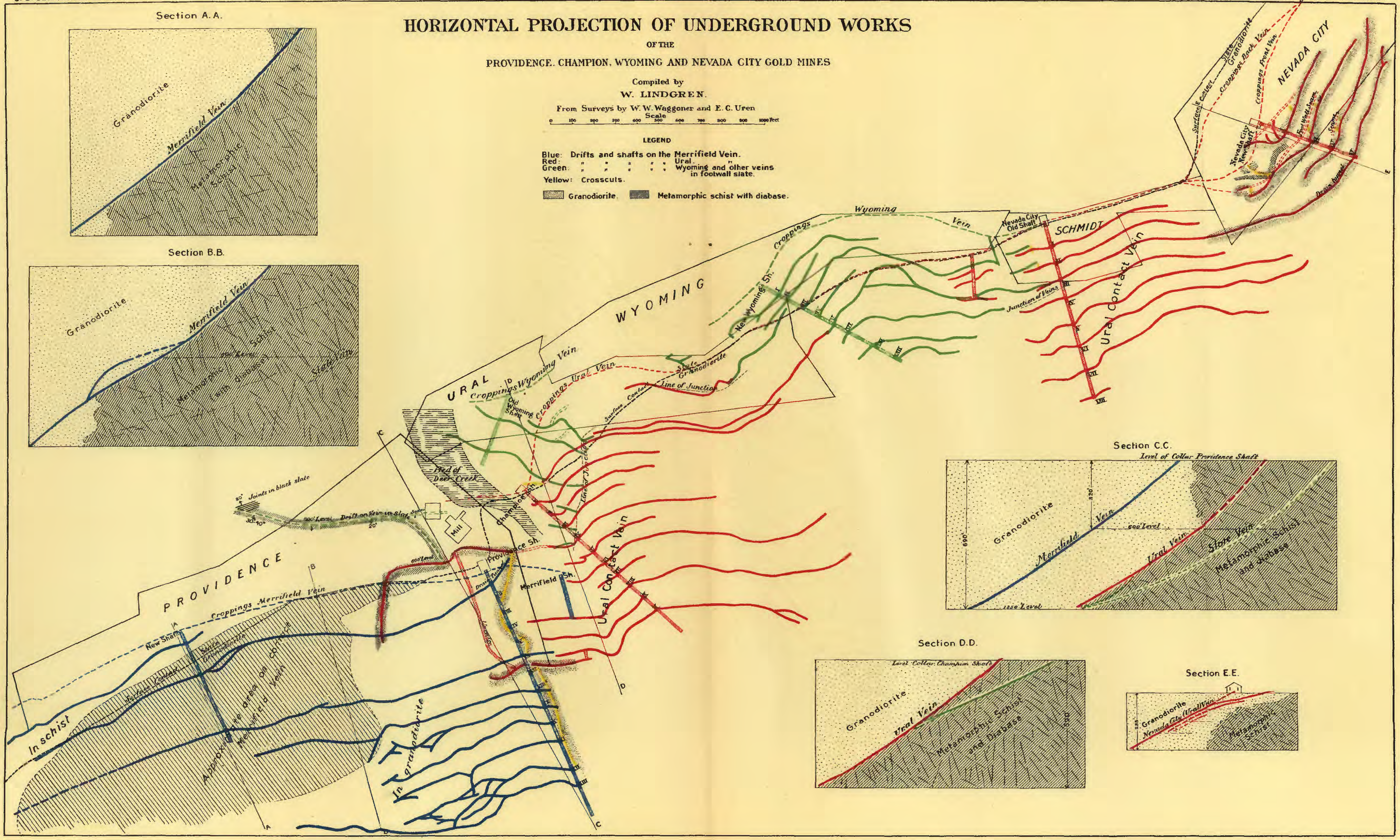
The Spanish mine is located 1 mile north of Deer Creek. The pay shoot at this place has been worked in a somewhat extensive manner only during the last few years. The property is developed by a shaft, at present 400 feet deep, and the ore is worked in a 10-stamp mill. The Merrifield vein appears here with somewhat changed characteristics. It lies in granodiorite, striking north-northwest and dipping 45° E. The vein is exceedingly variable in thickness, sometimes swelling to 8 or 9 feet of quartz, with some intercalated masses of altered country rock, then again pinching to a mere seam. The granodiorite is crushed near the vein, sometimes schistose, and in some places traversed by seams of black clay parallel to the vein, a product of extreme crushing. The altered granodiorite is filled with pyrite to an unusual degree, but the mass contains very little gold. In extreme form the altered granodiorite is a soft white rock with a greasy feel, consisting of carbonates, residual quartz, pyrite in sharp cubes, and sericite in extremely fine and talc-like scales. Calcite occurs sometimes with quartz as large cleavage pieces. The ore, which is generally low-grade with occasional very rich bunches, consists of solid quartz with a moderate amount of pyrite, galena, and zincblende. Coarse gold rarely occurs and ribbon quartz is not often seen. The pay shoot, said to be 150 feet wide, pitches north on the plane of the vein at a steep angle.

North of the Spanish mine the vein forks and runs blind on the surface for some distance, but there can not be much doubt that the Mount Auburn mine represents its continuation northward.

The Mount Auburn mine.—This mine has not been worked for many years. In the mint reports of 1881 and 1883 it was said to be working, but it must have stopped soon afterward. The shaft is 400 feet deep on the incline, and various levels run northward. The vein is said to be 18 inches thick, and strong in sulphurets, the pay shoots being very irregular. North of Mount Auburn, at Ragon's, the vein splits up into several almost parallel branches. The vein was struck again in the workings of the old Empire gravel mine.

THE URAL AND WYOMING VEINS.

The Ural vein can be traced continuously on the surface from the Providence mine to the Chapman ranch, a distance of 7,000 feet, and probably also continuously from there to the Coan mine at the edge of the tract. For a considerable distance north of Deer Creek the vein follows the contact between granodiorite and slate, and shows


HORIZONTAL PROJECTION OF UNDERGROUND WORKS
OF THE
PROVIDENCE, CHAMPION, WYOMING AND NEVADA CITY GOLD MINES
Compiled by
W. LINDGREN.
From Surveys by W. W. Waggoner and E. C. Uren
Scale
0 100 200 300 400 500 600 700 800 900 1000 Feet
LEGEND
Blue: Drifts and shafts on the Merrifield Vein.
Red: " " " " " Ural. "
Green: " " " " " Wyoming and other veins in footwall slate.
Yellow: Crosscuts.
Granodiorite.
Metamorphic schist with diabase.
Section A.A.
Granodiorite
Merrifield Vein
Metamorphic Schist
Section B.B.
Granodiorite
Merrifield Vein
Metamorphic Schist with diabase
Slate Vein
Section C.C.
Level of Collar Providence Shaft
Granodiorite
Merrifield Vein
600' Level
Ural Vein
Slate Vein
Metamorphic Schist and diabase
1250' Level
Section D.D.
Level Collar Champion Shaft
Granodiorite
Ural Vein
Metamorphic Schist and Diabase
Section E.E.
Granodiorite
Nevada City (Ural) Vein
Metamorphic Schist
PROVIDENCE
URAL
WYOMING
SCHMIDT
NEVADA CITY
Croppings Merrifield Vein
Croppings Wyoming Vein
Croppings Ural Vein
Wyoming Vein
Croppings
Ural Contact Vein
Junction of Veins
Nevada City Old Shaft
Nevada City New Shaft
New Wyoming Sh.
Old Wyoming Shaft
Line of Junction
Champion Sh.
Providence Sh.
Merrifield Sh.
New Shaft
Mill
Bed of Deer Creek
Joints in black slate
Drift on Vein in Slate
Approximate area on contact Merrifield Vein
In schist
In granodiorite
Cropping Back Vein
Croppings Front Vein
Surface Contact
A
B
C
D
E

a remarkable tendency to throw out parallel stringers in the latter rock with slightly less dip than the main vein. In the Providence ground the vein has been worked during the last few years by means of crosscuts from the main shaft on the Merrifield vein. North of the creek the Ural vein has been worked for a long time, being known also as the New Years vein. Located in 1851, it was worked for many years without much success. Since 1881 the Champion Company has developed the vein, with excellent results; a 30-stamp mill and chlorination works are built on the property.

In the *Providence mine* the vein has produced a large amount since 1893. In the Champion ground the output has also been large for a number of years, the mint reports crediting that mine with sums ranging from $77,000 to $158,000 in the years 1889 to 1892. The whole production of the Ural vein can not be stated with accuracy, but is probably not less than $2,000,000.

On the surface the vein first appears near the Providence chlorination works, in slate; crossing the creek, it is next seen at and above the Champion Hoist, here on the contact. Making a sharp bend to the west, largely caused by the rapidly rising hill, it continues north, at first not strictly on the contact, for immediately to the east there are a couple of hundred feet of very highly contact-metamorphosed slate mixed with granitic dikes, before the main contact is reached. Soon, however, the often heavy quartz croppings lie distinctly on the contact, and continue so at least up to the Nevada City southern shaft. Though the surface is very much decomposed, the croppings may be traced with considerable accuracy by aid of the frequent cuts and tunnels.

The average dip of the vein is 35° E., and it may be said to vary between 30° and 40°. Near the 600-foot level in the Providence mine it reaches the contact, and follows it strictly between that level and the 1,250-foot level, the lowest at the time of this examination.[1] The rich pay shoot between these levels lies along the upraise not far south of the main Providence shaft. Only on the 600-foot level has the vein been followed to the southward, and the exposures there are of great interest. The crosscut is in hard, massive granodiorite; the vein lies directly on the contact, with strong evidence of movement and crushing of both rocks. Southward, the granite soon leaves the hanging wall and the vein closes down to a persistent and distinct seam. The drift is now in a hard, massive, dark rock, containing occasional small granodiorite dikes; this rock is a considerably decomposed diabase, containing calcite and pyrite, and is evidently a body within the slate, which does not show on the surface. Six hundred feet from the crosscut the seam bends around to the east and becomes very much less distinct at the end of the drift, which is all along in the same diabasic

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[1] In 1895, a crosscut, started from the 1,800-foot level on the Merrifield vein, reached the Ural vein in about the same distance as on the 1,250-foot level. The vein is at this depth still on the contact.

decomposed rock. Three hundred and fifty feet from the contact, branch seams start to the east and west; the one to the east has been followed for almost 1,000 feet; it soon bends south again and enters the normal black siliceous slate having a pronounced jointing dipping west; the seam opens to a well-defined vein with as much as 16 inches clean quartz, and dips from 20° to 30° E.; no ore shoots have been found on this vein.

This level has been described in more detail because it is a remarkable instance of the sudden ending of a strong and heavy vein.

The strong pay shoot between the 600-foot and the 1,250-foot levels is about 150 feet wide and dips with the vein. Over this considerable area the vein is from 2½ to 3 feet wide, showing only white quartz mixed with much sulphurets. On both sides of this quartz lie 1 to 4 inches of soft black clay; and in the hanging wall there are usually several feet of greenish-gray, schistose, and crushed granodiorite impregnated with calcite and pyrite. In the foot wall there are also ordinarily from one to several feet of soft, black, crushed, slaty material, derived from the somewhat carbonaceous, contact-metamorphosed schists. The quartz shows no comb structure, but very clearly a ribbon structure, chiefly due to deposition of the sulphurets in large, irregular, roughly parallel masses.

The quartz divides easily in plates from 1 to 2 inches wide, and a close inspection will reveal a slight striation on these sheets, indicating a sheeting of the vein subsequent to its deposition. Small secondary fractures, filled with pyrite, sometimes cross the vein. The vein in this pay shoot is clearly and unquestionably a once open space filled with quartz and sulphurets. Near the 1,250-foot level the vein throws out flatter stringers in the foot wall, with good ore. The "slate vein" found on the 600-foot level is undoubtedly a continuation of one of these stringers. The percentage of sulphurets varies from 5 to 8 per cent; occasionally very heavy masses are found, containing $100 and above per ton. The sulphurets found are pyrite in predominant quantity, galena, zincblende, and chalcopyrite; there is very little arsenopyrite.

A considerable mass of altaite, or telluride of silver and lead, was found in 1894, and was accompanied by free, coarse gold, not otherwise usual in this ore. A little molybdenite also occurs. The concentrated sulphurets contain more silver than gold, the relation being 3.5 ounces of silver to 1 ounce of gold, but in the whole output of the mine the gold predominates by weight as well as by value. The gold obtained by amalgamation is 832 fine. Heavily sulphureted ore was found to contain 5 ounces of gold and 10 ounces of silver.

In the *Champion mine* the character of the ore is very similar to that just described. The sulphurets average 5 per cent and contain from 4 to 7 ounces of gold and 10 to 15 ounces of silver per ton.[1] There are

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[1] Eleventh Ann. Rept. State Mineralogist.

several pay shoots of lower grade north of the shaft, and one richer to the south of it; the shoots in general dip north on the vein at steep angles. The grade of the sulphurets and the ore is about similar to that just described. A little molybdenite has been found in the vein here also.

The heaviest body of quartz known in the mine lies in that peculiar sharp bend in the vein to the south of the shaft. In this place were noted 10 feet of massive quartz, with much sulphurets in irregular distribution, not ribboned.

The Champion mine being closed on account of legal injunction during the time of the examination, the opportunities for examination were not so good as might have been desired. Along the shaft and in the several levels in the vicinity of the shaft the Ural vein certainly lies on the contact between slate and granodiorite, and it is stated by all conversant with the character of the vein that the whole deposit, as far as known, lies on this contact. In special cases it may not always be easy to decide, but in general there is no difficulty in distinguishing the crushed slate from the granitic material. On the whole, the vein is very much like the Merrifield and the Ural in Providence ground. There is always a "formation" of crushed, more or less schistose material from 8 to 10 feet thick; the pay—that is, the quartz—may vary from a mere seam up to 10 feet in thickness.

A continued strong tendency to throw out branches in the foot-wall slate is noted in the Ural vein. Immediately north of the creek lies the Wyoming vein, a branch worked many years ago. This vein has a more northwesterly strike than the Ural, dips about 25° E., and distinctly joins the Ural along a line running east-west in horizontal projection. Some distance north another "slate vein," also called the Wyoming, and which may or may not be the same as the one just mentioned, appears, and can be easily traced up to a point at the South Nevada City shaft, where it joins the main Ural vein. On this vein, which dips flatter than the Ural and will eventually join it, a shaft has been sunk to a depth of 900 feet on the incline; the principal work was done between 1880 and 1890. The vein lies entirely in brownish, somewhat flinty, contact-metamorphosed slate, often filled with pyrrhotite. The width is irregular, averaging 2 feet; the sulphurets amount to 2¾ per cent; the pay shoots are very irregular, but a large amount of ground on both sides of the shaft has been stoped.

In the *Nevada City mine* (*Gold Hill Mining Company*) the Ural vein has been extensively worked since 1879, and after a short interval of inactivity work has recently been resumed on it with excellent success. The mine is opened near the southern end of the claim by a shaft 1,000 feet deep on the incline; but no work is being done at that place at present. The new shaft is located 1,100 feet north-northwest of the old one, and is at present 500 feet deep. Pl. XXI shows the extent of the works. The mine is said to have produced $600,000. (Nevada County Mining Review.)

The slate vein and the main Ural vein, uniting at the southern shaft, continue northward, the exposures on the surface at first being unsatisfactory; it is said, however, that the vein followed the contact for some distance.

Seven hundred feet north of the shaft the vein forks. One branch continues northward in the granodiorite and is known as the Muller and Walling; a small incline shaft has been sunk on a branch of this vein a short distance south of the main road. Though the outcrops are unsatisfactory, it is probable that the Muller and Walling makes a bend and continues to connect with the "old mine" indicated on the map, northwest of the Spanish mine.

Another and smaller branch runs out in the granodiorite, makes a bend, and soon returns to the main vein both on the strike and dip. The main branch also leaves the contact and makes a sharp bend to the northwest, soon changing to west-northwest, and continues running a short distance away from the contact and nearly parallel to it. In the old shaft the vein dips 32° E. The workings are not accessible, but it is stated on good authority that the whole vein here lies on the contact. In the new shaft beyond the bend the vein dips 25° E., the upper part of it being still flatter, for the outcrops lie a considerable distance back of the shaft. At the new shaft the vein lies entirely in granodiorite, except at one place in a crosscut a short distance south of the shaft in the third level, where a projecting mass of fresh, hard, quartzose schist reaches the foot wall. A sharply defined dike of granodiorite is contained in this schist. The hanging and foot walls are generally well developed, the space between them, several feet wide, being occupied by a crushed and altered granodiorite. In many parts of the mine there are several parallel seams, accompanied by crushing, back of the front vein. Going south in the drain tunnel, one finds the contact between granodiorite and the schist or slate at the point indicated on the map, at the first shoot of the old workings. The further extension was not accessible at the time of the investigation.

The vein is ordinarily from 1 to 2 feet wide. One body of quartz, with a width of 12 feet, was found on the fifth level, very soon, however, shutting down again. Immediately on the foot wall there usually lies a soft clay 1 or 2 inches thick and made up of finely ground up material. The ore is in general a massive quartz, with sulphurets in entirely irregular distribution. Only rarely is a ribbon structure met with. Small druses and vugs with quartz crystals are common. Coarse gold is seldom seen. The fineness of the gold averages 810. The percentage of sulphurets, varying greatly, may average 2½ per cent. The sulphurets, consisting of prevailing pyrite with chalcopyrite and less galena and blende, are rich, containing an average of 7.5 ounces of gold and 5 ounces of silver. Hessite, or telluride of silver, and molybdenite have also been found.

Nearly all of the quartz in the Nevada City mine is pay ore, ranging from $10 to $50, so that the stoped areas practically indicate all important quartz bodies on the vein. In the southern part of the mine there are four ore shoots up to 200 feet wide and dipping somewhat to the north on the plane of the vein. In the northern part the principal pay shoot lies to the north of the shaft and, though more irregular, still shows an indication of a northward trend.

Beyond the Nevada City the Ural vein can be followed across the hill to Chapman's ranch, where it is said to have been exposed by a small shaft. It is probably continuous to the Coan mine, where the vein carries considerable chalcopyrite, and has been opened by an inclined prospect shaft. It here enters the aplite area and its outcrops are not satisfactorily exposed.

It is thus certain that a large part of this vein from the Providence to the Nevada City follows the contact, and it is probable, according to the information available, that practically the whole vein between the points indicated follows it. Considering that the whole character of the vein indicates violent disturbance, the only reasonable explanation of this fact is that an overthrust fault has taken place along the vein, resulting in a displacement of at least 1,200 feet, measured along its dip. In other words, the hanging wall has moved up relatively, pushing the granodiorite over the slate and producing a wide zone of crushing and schistosity. This movement has chiefly been confined between the Nevada City mine and the Providence. It appears that near the former mine the movement has been distributed on the branching seams and gradually decreased. A similar distribution of the movement has taken place in the Providence mine, and it is probable that the sharp bend in the granodiorite contact between the Providence and Champion is due to movement on one of the cross seams. It is certainly a remarkable thing to find a large fault ending so suddenly. The rocks in the southern part of the Providence ground bear evidence of having been subjected to a great wrench. If these conclusions are correct, the Ural vein will soon be found to leave the contact and continue in granodiorite, for the fault can hardly have been much over 1,200 feet. This overthrust movement along the Merrifield and the Ural veins has evidently, between the Providence and the Nevada City mine, had the effect of pushing the contact westward a distance of from 800 to 1,000 feet. While it is reasonably certain that an overthrust has occurred on both veins, the evidence in the case of the Merrifield vein is more conclusive than that from the Ural vein.

JOHN BULL, SEVENTY-SIX, AND KIRKHAM VEINS.

The first two of these veins lie to the north of Coan's shaft, crossing Rush Creek. Some good ore is reported from a small pay shoot on the Seventy-six, while much low-grade ore is said to be found on John Bull. A 400-foot tunnel was run on this vein in 1866. The Kirkham has a very unusual northeasterly strike and a northwesterly dip of 60°. A good pay shoot was discovered on this vein in 1895. The country rock is diorite, containing many little pegmatitic dikes. The mine is located near the line where that rock gradually changes and is more quartzose granodiorite. In the pay shoot, which appears to be about 200 feet long, the vein shows 2 to 3 feet of somewhat decomposed quartz, with perhaps 2 per cent of sulphurets. The quartz contains some chalcedonite. The walls are very distinct; a few inches of clay with polished and striated surface lies next to the vein. On account of deep surface decomposition, the Kirkham can not be traced far southwest, but traces of gold are said to be found all through the red soil on the sonthwest slope of the hill.

THE SEAM BELT.

From Deer Creek up toward Indian Flat, 700 to 1,500 feet to the west of the Ural vein, extends a belt along which the rock—contact-metamorphosed schist, amphibolite, and diorite—is extensively sheeted by a system of joints generally dipping west at an angle of 20° or less. This jointing may be seen near the slate ledge in the 600-foot level in the Providence, and in the bluff on which the Home shaft is located. At this latter place it is very distinct, especially in the schist on the east side. A dike of diabase appears to have been faulted by these joints, the hanging wall having moved upward relatively. There is also a less well indicated system of fissures dipping east. Again, in the hydraulic pit west of the Nevada City south shaft, the jointing is well shown in the perpendicular wall of softened micaceous schist, and another system of joints is nearly horizontal.

On these seams a little quartz with very large amounts of coarse gold is often found. The hill to the west of the Nevada City mine, called Red Hill, from the deep, red, residual soil covering it, is honeycombed by little shafts and drifts on these little seams. While a dip to the west is most common, yet flat seams or seams dipping east are also met with. On the west side of the hill, near the contact of amphibolite and micaceous schist, the surface decomposition is very intense; it takes a practiced eye to follow the seams, scarcely marked in the soft red mass of decomposed rock, and often containing concretions of limonite. Along many seams gold is found in large pieces and plates; in 1895 two men are said to have panned out $3,000 in ten days from one of these seams. In the above-mentioned hydraulic pit a successful attempt has been made to wash by the hydraulic process the whole decomposed mass. There is an opinion current that these seams will in depth unite to a larger vein, but no good reason can be found to support such a view.

The *Black Ledge* is a hard bench of micaceous schist on the western side of Red Hill, carrying a little pyrite, the decomposed croppings of which are said to contain a little gold, probably, however, derived from narrow seams.

The seams are found again on the hill west of the Wyoming mill, and in the continuation of this belt south of Deer Creek the *Home* and the *Cadmus* mines are located. In the former several small veins have been found, dipping northwest, southeast, and east at angles of 30° to 40°, and some of them carrying coarse gold. At the Cadmus, the works of which were started in 1895, there are also several veins, one of them up to 1 foot wide and dipping west. Some coarse gold has been found on them.

ORO FINO, YELLOW DIAMOND, AND OTHER CLAIMS.

Though the great Ural vein can not be traced much farther than to the limits of the special sheets, there are to the west-northwest of the Coan shaft several veins, usually dipping east and extending down toward the river. None of them follow the contacts, and, as the sketch, fig. 20, shows, they are inclosed in different kinds of rocks. The Oro

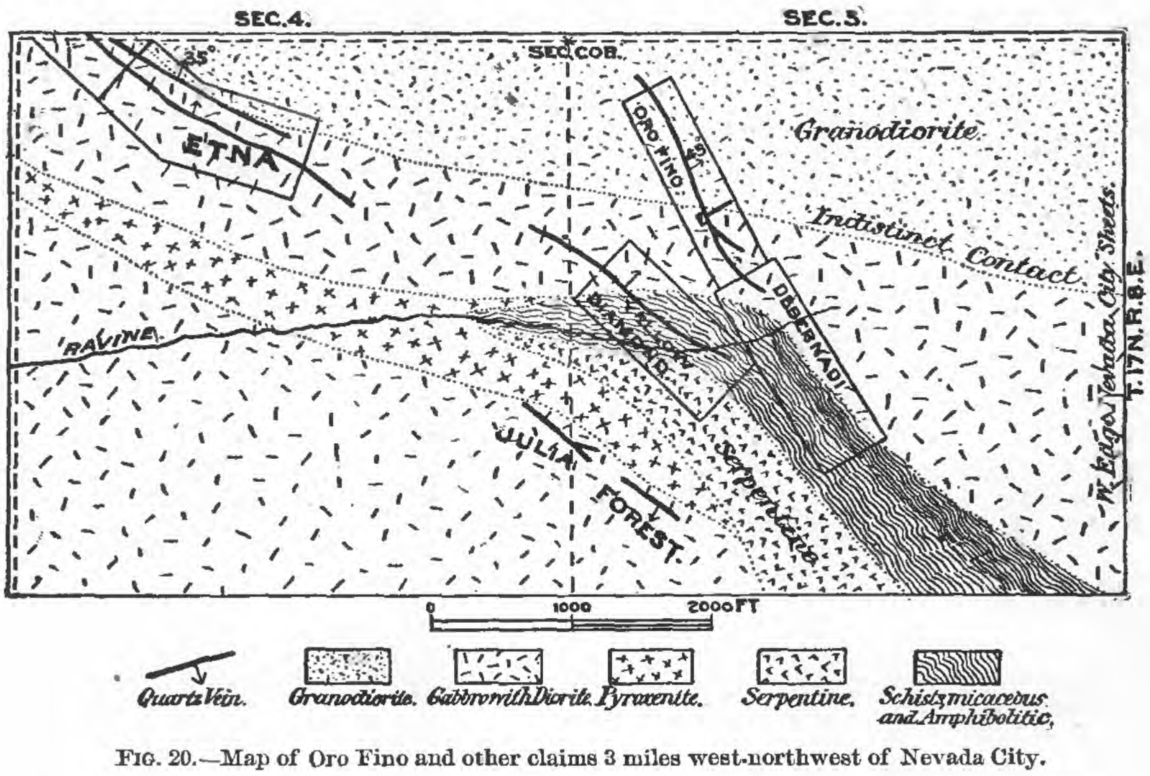

FIG. 20.—Map of Oro Fino and other claims 3 miles west-northwest of Nevada City.

Fino is the most important, and is developed by a shaft 300 feet deep on the incline. The vein dips from 45° to 32°, and strikes north-northwest. The width is said to be about 2½ feet, and there are three pay shoots, one north of the shaft, one at the shaft and 100 feet wide, and finally one narrow but rich shoot south of the shaft. The northern part of the vein lies in granodiorite, while at the shaft it is in a granular rock closely allied to a gabbro. There is a small amount of sulphurets. The Yellow Diamond has a northwest strike and lies chiefly in amphibolitic schists, with serpentine not far away in the foot wall. Several smaller shoots of ore have been found on the Yellow Diamond. In one place the vein is cut and faulted by a steep cross fracture, striking east-northeast. The Julia is a heavy, perpendicular, thus far barren vein; it lies in gabbro and carries some copper pyrite. The Forest vein dips steeply to the southwest, lies also in gabbro, but near the pyroxenite, and has produced some quite high grade ore containing considerable azurite and malachite. The Dement and Etna are heavy veins, not developed to any extent, and lie in diorite or gabbro near the granodiorite. They also carry chalcopyrite. The Dement can be traced a few hundred feet beyond the limits of the sketch, down on the steep slope toward the Yuba River, but has not been found as far down as the river.

The *Mount George* lies on the headwaters of the main branch of Rush Creek, a short distance north of the main road to Newtown, 3 miles out from Nevada City. It is outside of the special sheets. On the property is a large vein of low-grade ore, striking slightly north of east and dipping about 62° S. North of the vein, two flat seams have been found, containing a ferruginous quartz, dipping in toward the main vein, and some very rich pockets. The two shafts developing the property are less than 100 feet deep.[1] The country rock is gabbro, forming the continuation of the Pleasant Flat diorite area.

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[1] Twelfth Ann. Rept. State Mineralogist.

CHAPTER XVI.

DETAILED DESCRIPTIONS—(CONTINUED).

GRASS VALLEY DISTRICT.

The veins of the Grass Valley district, though of great variety in dip and strike, show in their ores and structure a general similarity. The veins are, as a rule, not wide, but the shoots carry high-grade ore. There is very little silver, the Omaha system alone carrying a notable quantity of that metal. Except in that same system, the amount of sulphurets is also below 3 per cent. Pyrite with a little galena, chalcopyrite, and zincblende form the sulphurets. Only in the Osborne Hill system and in the Forest Spring veins is there any considerable quantity of arsenopyrite present. Coarse gold is very frequently met with in the veins.

The Grass Valley veins may be classed in several groups or systems.

THE IDAHO SYSTEM.

The veins in this system, parallel to the great Orleans vein of Nevada City, have a strike ranging from east and west to west-northwest and east-northeast. The dip is usually steep, and may be either northerly or southerly; in certain of the veins, however, flatter dips are observed. The veins are often of greater width than those to the south of Grass Valley, and carry but a small percentage of sulphurets.

THE ALPHA, KENTUCKY, AND SPRING HILL VEINS.

The Alpha and Kentucky are two parallel veins one-fourth of a mile northeast of the Maryland. The developments are slight, consisting of an incline shaft 300 feet deep; the shaft on the Alpha, which is higher up the hill to the west, is 200 feet deep on the incline. The dip is 30° to 50° to the north, and the vein strikes west-northwest. The veins are in serpentine, but a dike of diabase appears near Wolf Creek in the hanging wall of the Kentucky. In Raymond's Report for 1873 the Kentucky is credited with a production of $5,000, the ore averaging $17 per ton.

The Spring Hill vein, about 1,500 feet north of the Maryland shaft, has been developed to only a slight extent by two inclines 200 and 300 feet deep. It is a strong, continuous vein, striking east-west, or in the western end west-southwest, so that if extended it would intersect the Eureka. The dip is 60° N. at its eastern end, changing to 30° on the summit of the hill. The vein lies chiefly in serpentine, but in its western part there is in the foot wall a rather heavy dike-like mass of an extremely chloritic and altered diabase. The Spring Hill is from 2 to 5 feet wide and contains a small amount of sulphurets in fine distribution. The ore is generally low-grade; though several smaller lots of high-grade ore were milled in 1870.[1] Some work was done on it in 1892 with encouraging results.

THE COE VEIN.

This deposit is on the west side of the road from Grass Valley to Nevada City, about one-half mile from the former. It has been idle for many years past, but was extensively worked twenty years ago. It is said[2] to have yielded $500,000. It is developed by a shaft 554 feet deep on the incline, and three levels run from the same. The vein,

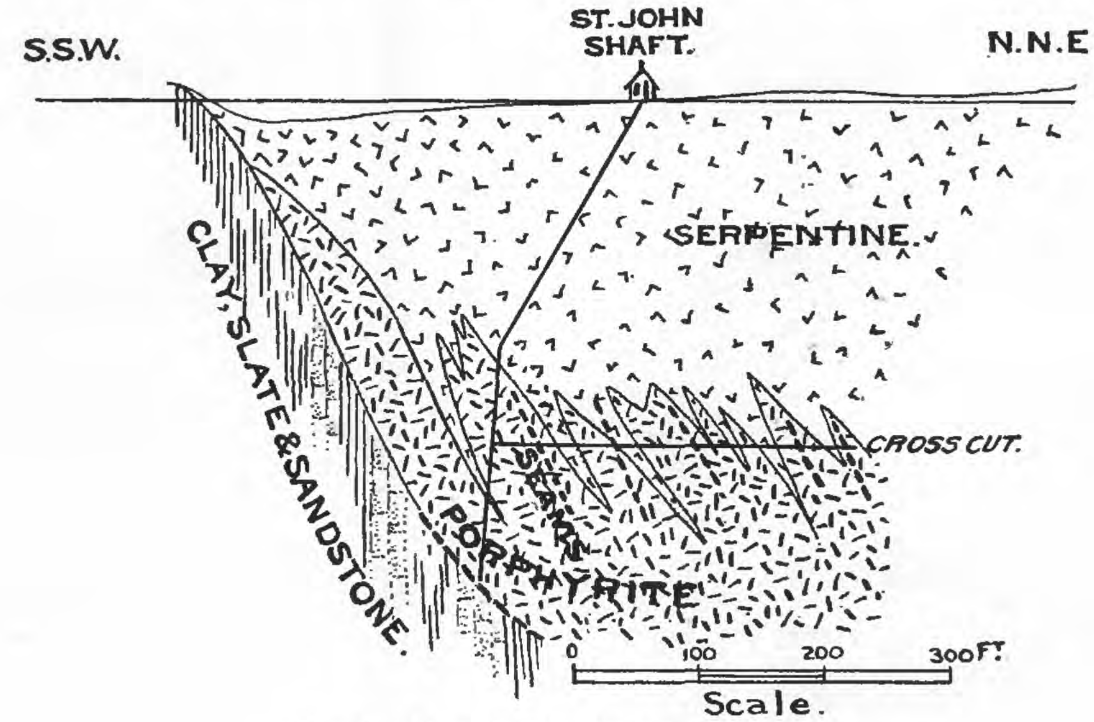

FIG. 21.—Vertical section through St. John shaft.

which lies in serpentine, can be traced for only 1,000 feet west of the road. The strike is parallel to that of the Idaho-Maryland, but the dip is 60° N. It is not, as often asserted, an extension of the vein just mentioned. The outcrops are remarkably strong, showing 3 feet or more of solid quartz. On the west it is said to continue up to the St. John, but there is not sufficient evidence to support this view. Some croppings show at the head of the gulch in which the Coe is located, but it is not beyond doubt the same vein. The ore is said to contain only 1 per cent of pyrite and galena. The extent of the pay shoot is not known; it is reported to pitch to the west.[3]

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[1] Eighth Ann. Rept. State Mineralogist.
[2] Nevada County Mining Review.
[3] Tenth Ann. Rept. State Mineralogist.

THE ST. JOHN MINE.

This property, which lies three-fourths of a mile north of Grass Valley, was actively prospected in 1893 and 1894, but is at present closed down. The geological features shown in the workings are of great interest. At the point where the shaft is sunk some quartz appeared on the surface, but no continuous vein could be traced. The shaft goes down to a depth of 220 feet, dipping south at 70°, and from there on to the bottom at a depth of 500 feet it is nearly perpendicular. The serpentine of the surface is found to be replaced by porphyrite, traversed by seams of serpentine (fig. 21). In the bottom of the shaft the contact with the black clay-slate was unexpectedly struck, and on this contact a quartz vein, in one place nearly 10 feet thick. Drifting east the heavy body of quartz soon contracted, and the relations at the face of the drift are illustrated by fig. 22. Between the slate in the foot wall and the serpentine in the hanging wall lie a few feet of slaty serpentine with stringers of quartz, the latter containing some galena and free gold. West of the shaft the vein, or at least a branch of it, goes in the clay-slate, but in a little crosscut in the foot wall it shows again the relations illustrated in fig. 23, the serpentine resting on the clay-slate and separated from it by a polished seam and a small quartz vein. All these facts point strongly to the existence of an overthrust fault along the contact of slate and serpentine. In a long crosscut, shown in fig. 21, a number of seams were met with, almost forming a sheeting of the porphyrite, and most of these carry a little free gold, as shown by prospecting the crushed matter in the pan.

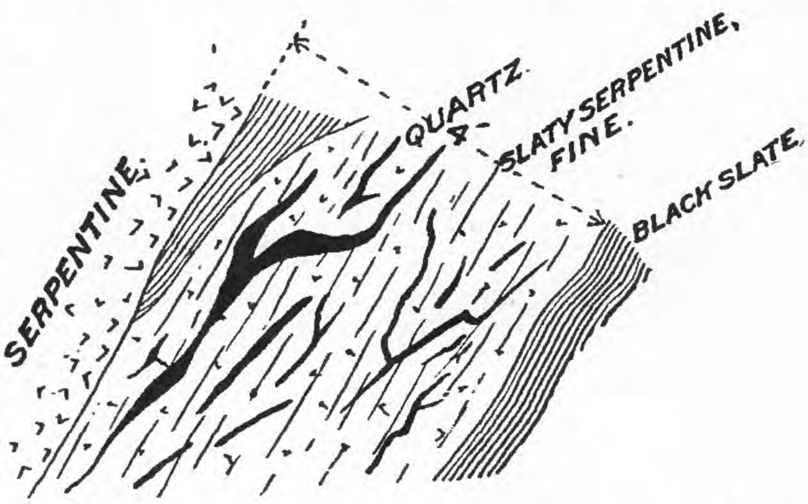

FIG. 22.—Vein in St. John mine, fifth level, 150 feet east of shaft.

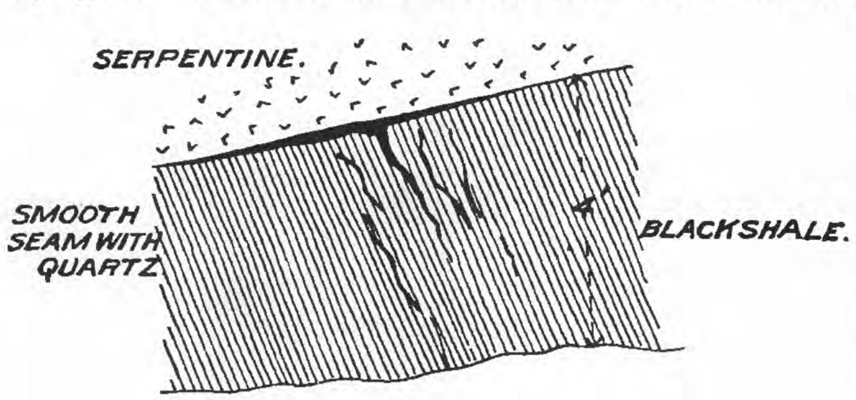

FIG. 23.—Vein in St. John mine, fifth level. 100 feet west of shaft.

THE EUREKA-IDAHO-MARYLAND VEIN.

The ore shoot of this interesting vein has been worked in the Eureka and the Idaho, and is at present exploited in the Maryland. The Eureka, on the western end of the vein, was located in 1851. The vein is indeed here conspicuous by heavy outcrops on the surface; these outcrops were, however, very poor, and from 1857 to 1863 the ledge was worked only to a depth of 48 feet, much quartz, of low grade, being taken out. Finally, in 1864, the vertical shaft was sunk to 100 feet and the main ore shoot encountered. On the Eureka ground the ore shoot was then successfully worked until 1873, when the yield began to decrease, and in 1877 the mine shut down after vain efforts to find the continuation of the shoot to the west. The adjoining veins of Mobile and Roannaise were also prospected toward the end, without success. The Eureka mine produced a total of $5,700,000. Several years the mine produced from 10,000 to 12,000 tons of ore per month, running from $23 to $60 per ton, and averaging $28, at a cost of mining and milling of $10 to $15 per ton.

The Idaho mine, located in 1863, adjoining the Eureka on the east, was worked but little until 1865. At that time a perpendicular shaft was started, striking the vein at a depth of 120 feet, but finding no good ore. In 1867 the shaft was sunk to 300 feet, at which depth the great pay shoot was found. From 1867 the same pay shoot was worked continuously until 1894, when the eastern limit of the Idaho ground was reached. The total output was $11,638,000, the tenor of the ore ranging from $12.76 to $35 per ton, probably averaging $20. The cost of extraction and treatment was from $8 to $10. The output in successive years ranged from a minimum of $183,450 in 1871 to $1,010,600 in 1873. From 1889 to 1892 it ranged from $480,000 down to $226,000. The combined production of the Eureka and Idaho is $17,338,000 in twenty-eight years.

Developments.—The Eureka was developed by a shaft which in 1871 had attained a depth of 725 feet on the incline, and which in the last years of operation was sunk to a depth of 1,200 feet. Below 600 feet, however, no good ore was found. The shaft was perpendicular to a depth of 317 feet, and then followed the pitch of the vein. The drifts extended across the width of the claim, a distance of 1,550 feet. The Idaho is developed by a shaft inclined about 70° from the horizontal, and which attains a perpendicular depth of 976 feet. A short drift extends to the east on that level to the collar of an underground incline, running obliquely on the plane of the vein at an angle of about 40° from the horizontal and attaining a total vertical depth of 2,180 feet, or an elevation of 360 feet above the sea level. From this incline shaft the levels extend eastward to the end of the claim. The Maryland mine is working at present on the same pay shoot continuing eastward, using the old Idaho shaft for the exploitation.

Outcrops and country rock.—The vein first appears in serpentine on the Eureka ground as very strong croppings of white, massive quartz. Toward the east, in the vicinity of the old Eureka shaft, indications of a chloritic and decomposed diabase appear in the hanging wall; the outcrops are very much less prominent, and are not seen at all east of the Idaho-Maryland shaft. A diabase dike outcrops in Wolf Creek, in serpentine, about where the vein would be expected. At the Idaho shaft a coarse-grained uralite-gabbro appears in the hanging wall, but a short distance east of the shaft the vein must outcrop in serpentine. It probably continues in serpentine all the way up to beyond the Maslin shaft, but until near that point no outcrops are visible; nothing definite can be seen on the hillside, which is covered by deep, red soil; it is possible that a diabase dike follows the vein here, too. At the Maslin shaft, however, the croppings of white quartz in serpentine are distinct, and there can be little doubt that these represent the vein in question. A short distance beyond the Maslin shaft the line of the vein, if continuing straight, would enter coarse, white gabbro, or it may bend a little southward and follow the line between serpentine and gabbro. The old Maryland shaft, 300 feet deep, was sunk southwest of the Maslin shaft to intercept the vein, but encountered nothing but serpentine. Three thousand feet southeast of the Maslin shaft the Chevanne shaft is now being sunk in the serpentine to find the continuation of the vein; nothing but serpentine has thus far been met with, at a depth of a few hundred feet. A quarter of a mile farther southeast, near the Brunswick mill, the Chevanne tunnel, 1,200 feet long, was driven in a northeasterly direction, but without result; the tunnel is in gabbro and serpentine. Small croppings, which may possibly represent the croppings of the Idaho-Maryland vein, have been found 650 feet north-northwest of the Chevanne shaft, near the contact of serpentine and gabbro. Under ground, the vein lies, in many places at least, on the contact of diabase and serpentine, but sometimes the determination of formations is not easy without crosscutting in hanging and foot walls. The average strike is N. 77° W., and the dip is about 70° S., occasionally, however, flattening out to 50°.

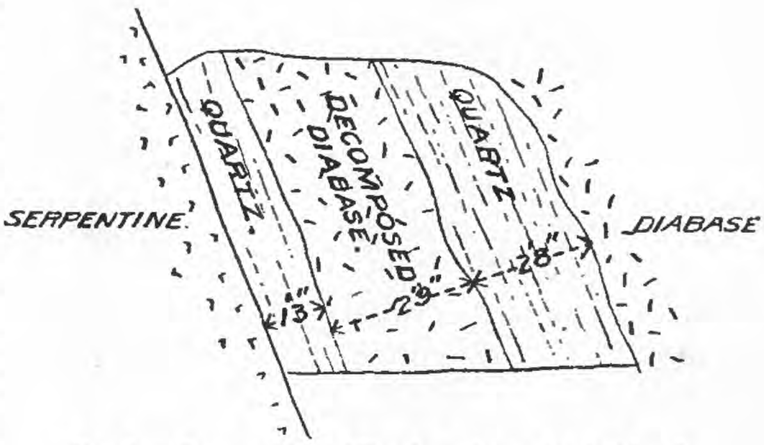

FIG. 24.—Cross section of Eureka vein, on 300-foot level.

In the Eureka ground there are, according to Professor Silliman, two veins, separated by a mass or dike of greenstone 30 feet thick. The smaller of these veins, on the south, has never been worked. The main vein lies, as indicated by fig. 27,[1] between a serpentine foot wall and

[1] Copied from Mellville Attwood in Phillips's Mining and Metallurgy of Gold and Silver, London, 1868.

a dike-like mass of diabase in the hanging wall. The vein is heavy, varying from a few inches to 6 feet, and averaging 3 or 4 feet of solid quartz. On the 300-foot and 400-foot levels in the Eureka a horse of decomposed diabase was met with, dividing the vein in two, as illus-

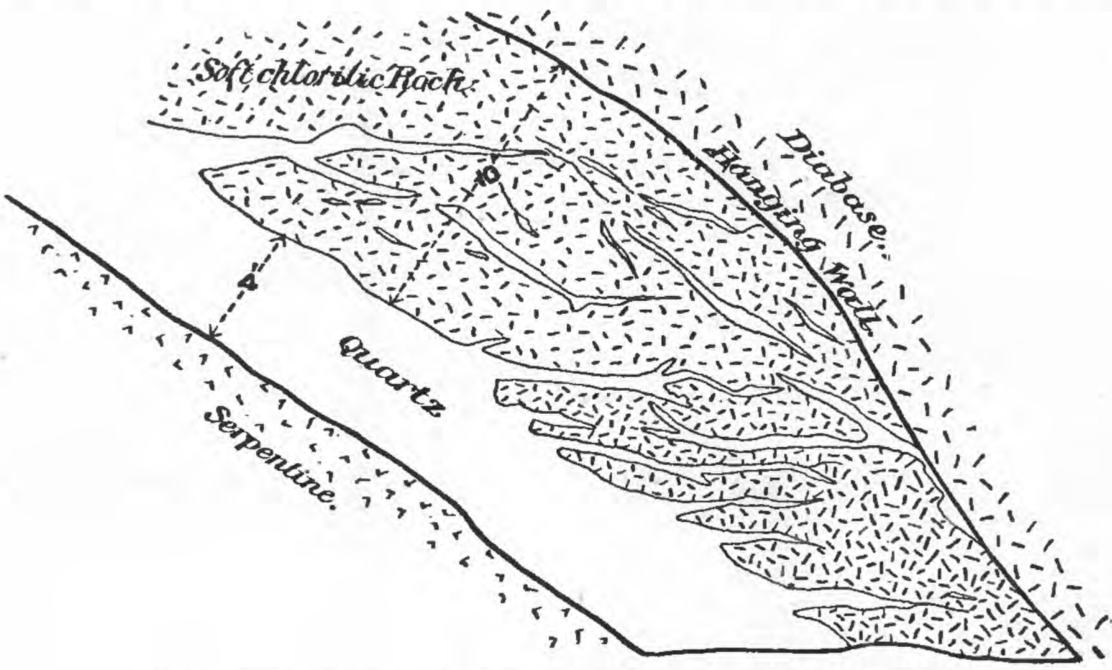

FIG. 25.—Cross section of Maryland vein in stopes above the 1,500-foot level.

trated in fig. 24.[1] The dip for the first 300 feet is 78°, which below decreases to 65° to 70°. This horse varies in thickness from a few inches to 6 feet, and is often filled with quartz stringers, so that the whole mass may be mined. In a few localities both layers of quartz

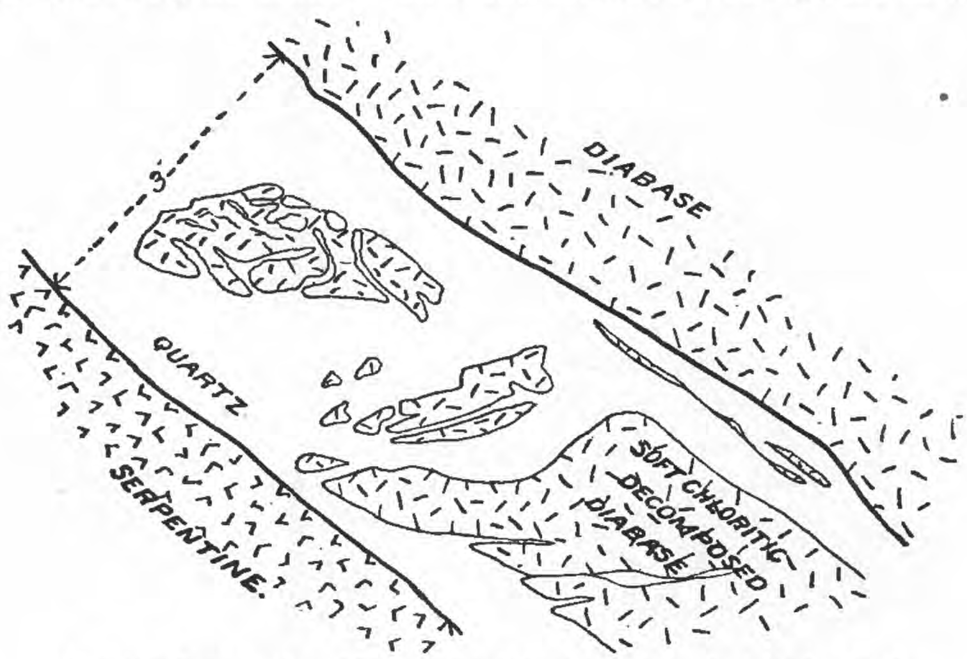

FIG. 26.—Cross section of Maryland vein in stopes above the 1,500-foot level.

come together in the width of the vein, without having the horse between. In these cases there is a line of quartz crystals visible which fill the narrow cavity sometimes left.[2] On the hanging wall there is a

[1] Copied from Melville Attwood in the Eighth Ann. Rept. State Mineralogist.
[2] Raymond's Report, 1872, p. 41.

distinct clay selvage. Concerning the western extension, Professor Silliman makes the following statement (Bean's Directory, p. 233): "The Eureka vein, going west, faults in the Whiting ground, and, having previously become almost vertical, has to the west of the fault a northerly steep dip."

In the Idaho and Maryland mines the vein is equally well defined; the dip is from 73° to 55° S., and the strike very regular; the width of the ore—that is, of the quartz—probably averages 2½ feet. The serpentine is often well exposed in the foot wall, but the diabase is not always distinct. Flaky, chloritic, or serpentinoid soft rock, filled with calcite and cubes of pyrite, often forms the hanging wall; comparatively fresh diabase was noted at the shaft in the seventh and fifteenth levels and at a few other places. A long crosscut, starting from the seventh level and extending 800 feet in the hanging wall, begins in diabase; 25 feet from the vein coarse gabbro begins to appear and continues for 200 feet, mixed with what are probably dikes of diabase; then southward to the face the crosscut is diabase, cut by seams in many directions, but not showing any distinct veins or mineralization. On the whole, the vein was very regular in width and character; in a few places it showed signs of splitting up, but soon increased in strength again. Such places were found in 1875 below the 800-foot level, when the hanging wall went down flat and the ledge broke up in stringers; again in 1882 and 1883 the ore became poor on the 1,100-foot level and the vein irregular; some distance east of the Maryland line, on the 1,500-foot level, the vein splits in two parts, but it has in every case been found beyond strong and reunited. The vein is frequently accompanied in the foot wall by a characteristic gangue of dolomitic rock, sometimes colored green by mariposite, which is to be regarded as a completely altered serpentine. These and other rocks from the Idaho-Maryland are described in detail in Chapter XI. Mr. Attwood states that this dolomite carries a little gold.

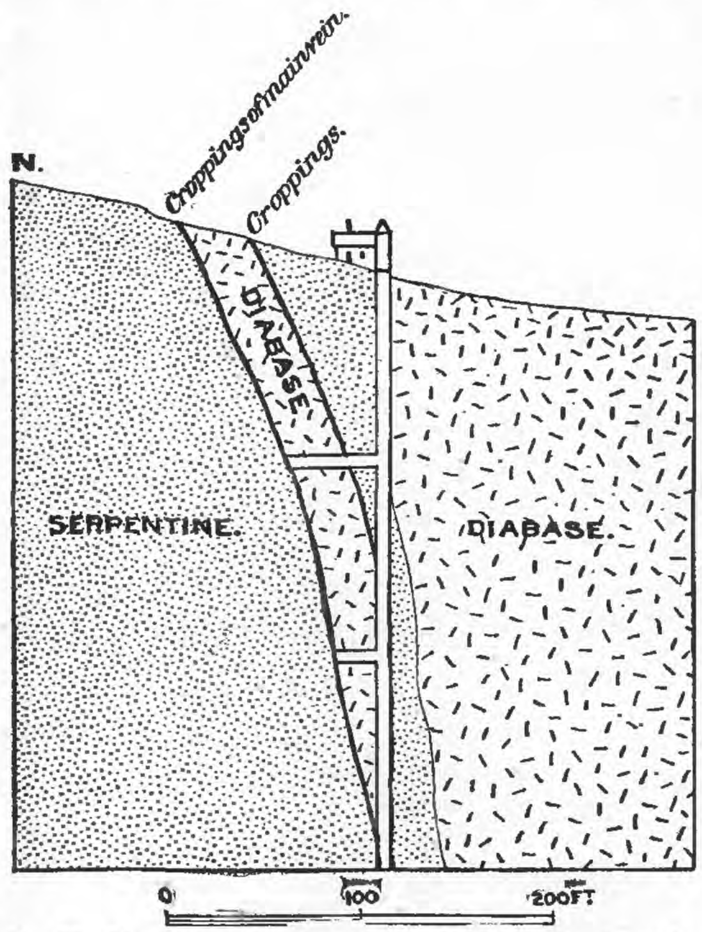

FIG. 27.—Vertical section through Eureka shaft, showing veins.

The ore.—The ore consists exclusively of the solid quartz in the pay shoot, except when the adjoining country rock is impregnated with quartz stringers, as sometimes happens. The chief value in the ore is in the free gold, which as a rule is in fine distribution. Sometimes, however, rich "specimen rock" is met with showing abundant coarse gold. The ore has varied, as stated, from $60 down to $10 and $13 per ton, but an average would probably be about $20. It would appear as if the western part of the pay shoot were somewhat richer than the extension toward the east. The gold is 848 fine; the amount of sulphurets is small, having varied from 1¼ per cent in the Eureka to three-fourths of 1 per cent and 2 per cent in the Idaho and Maryland. The value of the concentrated sulphurets is about $100, sometimes reaching $400. The amount of silver in the sulphurets is small, being stated to be 1.5

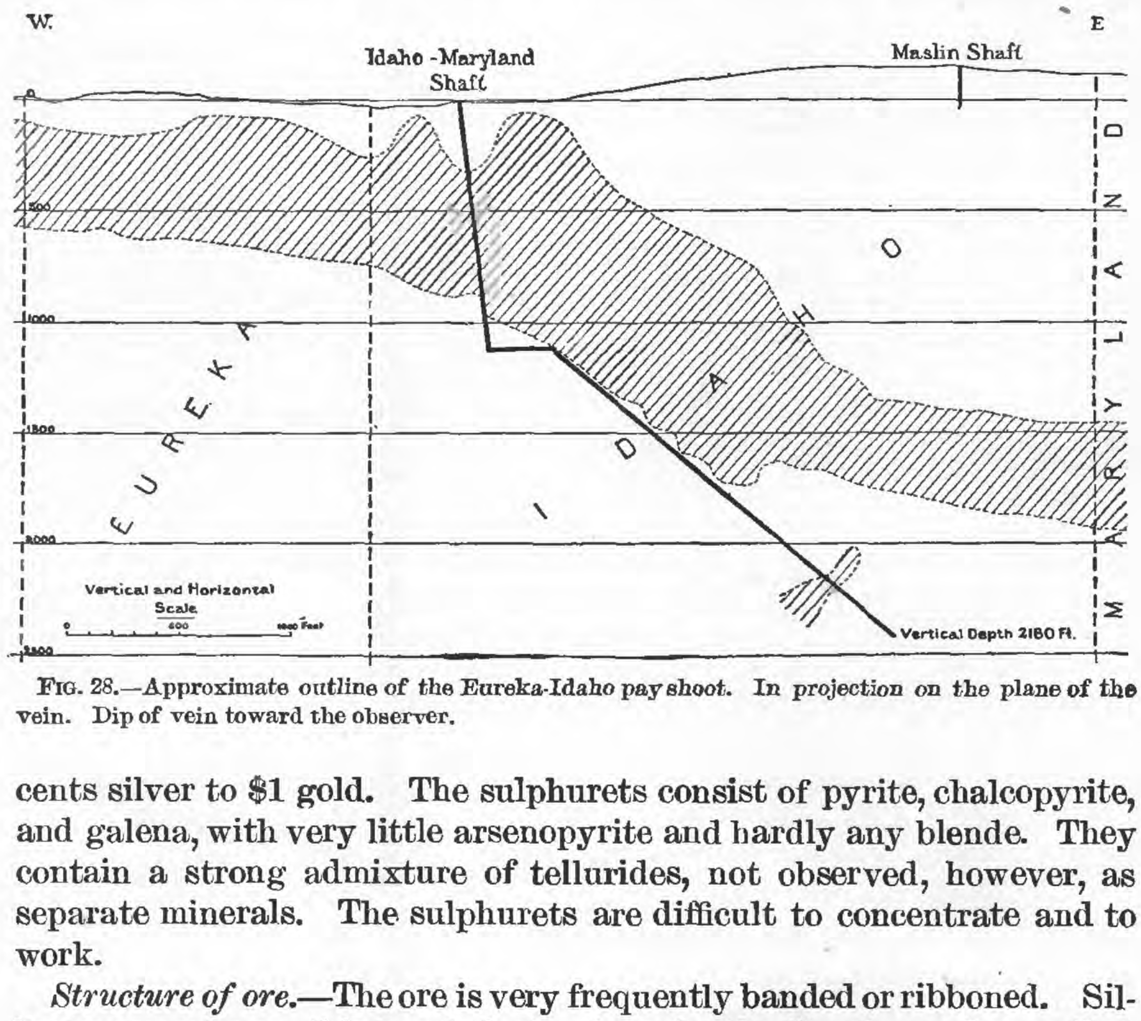

FIG. 28.—Approximate outline of the Eureka-Idaho pay shoot. In projection on the plane of the vein. Dip of vein toward the observer.

cents silver to $1 gold. The sulphurets consist of pyrite, chalcopyrite, and galena, with very little arsenopyrite and hardly any blende. They contain a strong admixture of tellurides, not observed, however, as separate minerals. The sulphurets are difficult to concentrate and to work.

Structure of ore.—The ore is very frequently banded or ribboned. Silliman remarks on this banded structure in the Eureka and says that the joint surfaces are often coated with gold. A banded structure by arrangement of the pyrite in parallel streaks is also noted. Pls. XI and XII[1] show the structure of the Maryland vein. In Pl. XI the ribbon structure is illustrated, due without much doubt to the sheeting of the vein subsequent to its formation. In Pl. XII the vein consists of

[1] From photographs by Victor Dorsey, the superintendent of the Maryland, whose untimely death in 1895 was due to a falling slab of the treacherous hanging wall in his mine.

solid white quartz with no indication of ribboning by sheeting or deposition. Fig. 25 shows on smaller scale the locality of which Pl. XII is a part. Fig. 26 shows the structure of the vein at a place in the stope not far distant from the fifteenth level.

Pay shoot.—The pay shoot of the Eureka-Idaho vein is one of the most remarkable known in vein geology. Its extent and character are shown in fig. 28. Over the whole shaded area it is safe to say that the vein averaged 2½ feet of solid quartz. Outside of these limits the vein grew poor rapidly, and frequently closed down to a mere seam. A vein 2 and 3 feet thick is, however, found in many places outside of the pay shoot, and the physical characteristics of the vein remain the same. Of the eighth level in the Eureka the superintendent stated that the walls were good and regular and 4 feet apart, but the vein was small and very poor. A small pay shoot was found in the deepest part of the Idaho shaft; it was followed for some distance, but eventually proved too small for successful exploitation.

The principal pay shoot has thus been followed for almost a mile with an average dip of 15° E. on the vein and an average width of 600 feet. There is no reason why it should not continue for a long distance eastward, provided the vein does not enter the serpentine; if it does that the probability is that the vein will be found to split up in stringers. The fact that over a large area the vein lies in the serpentine in the foot wall and in diabase in the hanging wall would lend some strength to the view that a considerable overthrust had taken place along it, for the contacts between different rocks are as a rule far from regular. While this is likely, it can not be said to be proved.

THE SOUTH IDAHO VEIN.

Located 2,000 feet south of the Idaho and parallel with it in strike and dip, this vein is developed by a tunnel on the east end and a shaft 100 feet deep on the west. The vein lies in a peculiar mixture of dark-green diabase with coarse uralite-gabbro, in places sheared and serpentinized, the former probably forming a network of dikes in the latter. The zone of thermal alteration is wide, as evidenced by the bleached country rock greatly impregnated with calcite and pyrite, and sometimes colored green by mariposite; seams with large cleavage pieces of reddish calcite also occur. In one case gold has been noted inclosed in calcite. On the foot wall was a distinct and rich stringer of quartz with coarse gold, galena, blende, and pyrites. At a depth of 60 feet this stringer extended out in the hanging wall and splintered up, the veinlets being rich in coarse gold, while the foot wall continued down.

THE BRUNSWICK GROUP OF VEINS.

To the southeast of the Idaho-Maryland is a group of parallel veins which evidently belong to the Idaho system, though the strike has turned more northwesterly. The Brunswick (also known as the English, or O'Connor), with a strike of N. 50° W. and a southwesterly dip which down to 400 feet is 45°, then becoming 60°, and finally at 600 feet 70°, was located early and has been worked with varying success for a long time, the upper levels containing some good ore shoots. For the last seven years the mine has been extensively prospected, and some good bunches of ore have recently been found in the lowest level. The mine is developed by a shaft 700 feet deep on the incline, and drifts extending 300 feet toward the west. The vein is contained in a chloritic schist derived by dynamo-metamorphic processes from a porphyrite-breccia, and intersects the strike of the schist at an acute angle. There are usually two well-defined walls, 2 to 4 feet apart. The space between the walls is only locally wholly filled with massive quartz, being generally occupied by soft chloritic schists, extensively altered by hydrothermal processes; the schists are either parallel to the walls or, as is frequently the case, broken and irregular; they contain streaks and ramified veins of massive quartz (fig. 29), which sometimes increase in thickness and occupy the whole space between the walls. East of the shaft the vein closes down to a mere seam. Free gold is rarely visible in the quartz, and the sulphurets, which generally are rich, consist of pyrite, chalcopyrite, and galena.

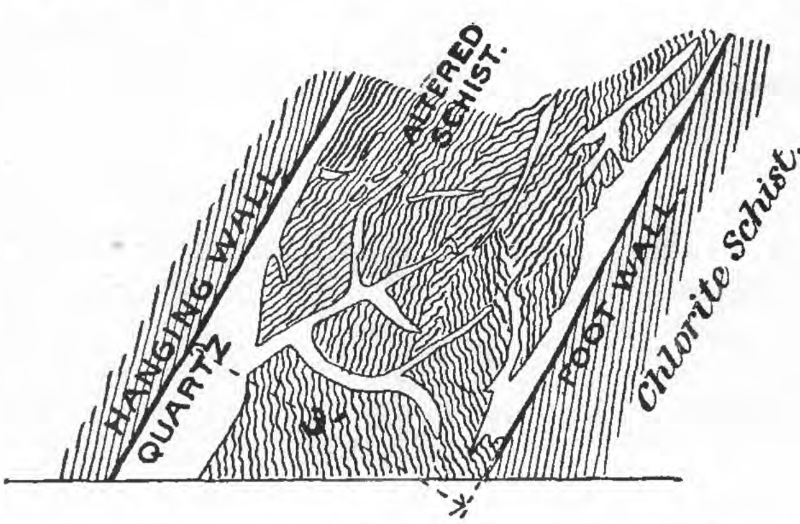

FIG. 29.—Cross section of the Brunswick vein, on 700-foot level.

The Gold Point is a vein parallel with and south of the Brunswick. The heavy croppings, dipping 70° S., can be traced for over 2,000 feet. It is opened by a tunnel from Wolf Creek connecting with inclines from above. To the west of the tunnel the vein is very heavy and contains large masses of low-grade ore. The country rock is a schistose porphyritic breccia, less chloritic than that of the Brunswick.

The Union vein, the croppings of which are visible in places on the north bank of Wolf Creek, is one of the earliest-located veins in Grass Valley. The ore was worked with an arrastra up to 1854. In 1865 mill and hoisting works were erected, and the mine was worked with profit until 1870. The total product is given as $250,000. From January 1 to August 1, 1869, the mine produced 7,200 tons, yielding $75,569, or about $10 per ton. The vein, which is continued in schistose porphyritic breccia, dips 50° S. and has been developed by a shaft 268 feet deep on the incline. The width is said to be considerable, averaging 3½ feet. The extent of the stopes is shown on fig. 30, taken from

Raymond's Report for 1869-70. The gold is 822 fine. Galena is said to predominate in the sulphurets.

The Cambridge vein is located on the south side of Wolf Creek. The Lucky and the Cambridge mines were located on this vein and worked extensively about 1865 to 1868. The Lucky mine, on the west, had a 15-stamp mill and was exploited by a shaft 400 feet deep on the incline, 10,000 tons of ore being extracted from 1865 to 1867. The Cambridge, adjoining on the east, was opened by a shaft 200 feet deep, and a 10-stamp mill was erected on the property; 75 tons of ore per week were crushed for a long time, averaging $20 per ton (Bean's Directory). The vein lies in chloritic schist, dips 50° SW., and is generally wide, averaging 2 to 3 feet. According to Professor Silliman, free gold is rarely visible in the ore. If these reports are correct, this vein, as well as the Union, may be rendered productive again. The gold is from 817 to 820 fine.

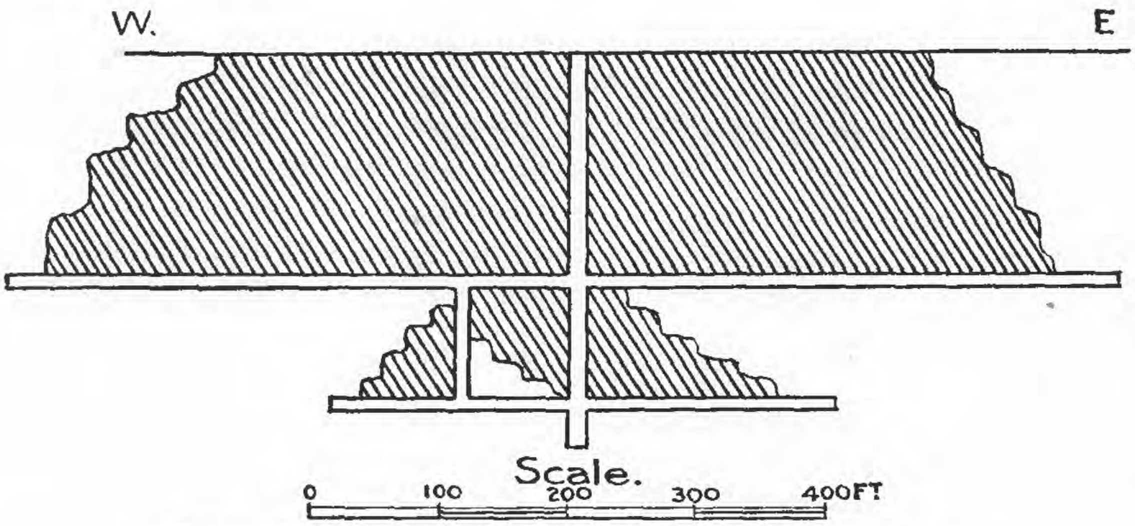

FIG. 30.—Longitudinal section, Union Hill mine, showing areas stoped.

The Francfort vein, about 800 feet south of the Cambridge, is said to have produced some good ore from the croppings.

THE CROWN POINT VEIN.

This deposit, located on the south side of Wolf Creek, half a mile east of the center of the city, has been worked at intervals since 1886. The production is stated to have been $130,000, of which $80,000 was found in one bunch of ore with much coarse gold. The shaft is 400 feet deep on the incline, with levels extending east and west, only the upper two levels being accessible in 1894. The vein, which strikes northwest and dips 70° to 80° N., lies in serpentine or serpentinized porphyrites, the width of quartz and vein matter varying from a few inches to 4 feet. There are considerable amounts of magnesic and calcic carbonates produced from the serpentine by thermal alteration. A thin sheet of quartz, still adhering to the foot wall near the shaft in the drift, shows beautiful polish, with nearly horizontal striation; in other places the striation in the foot wall is parallel with the dip. The serpentine of the hanging wall is filled with carbonates and pyrite; the ore carries coarse gold and 3 per cent of sulphurets.

The New Eureka shaft, 500 feet deep, was sunk about 1888, 900 feet northwest of the Crown Point shaft, to find the extension of the Crown Point vein. The shaft is inclined 80° N. down to 121 feet, and from that depth is vertical. The upper part of the shaft was in black slate and sandstone, changing at a depth of 150 feet to chloritic and serpentinoid rocks derived from porphyrite and diabase. Highly mineralized zones, rich in pyrite, and with some quartz, were met with at a depth of about 200 feet, but no well-defined vein.

A 20-foot crosscut to the north from the 200-foot level on the Crown Point has intersected a mineralized zone along a fissure dipping in part north, in part south, at steep angles. Along this fissure the country rock is chiefly serpentine, but black siliceous slates are also met with, usually highly impregnated with pyrrhotite. The ore is most unusual in character, differing greatly from the ordinary quartz veins, and consisting chiefly of calcite, pyrrhotite, chalcopyrite, with some ordinary pyrite; the sulphurets occur as heavy masses 5 to 6 inches thick along the vein, and a sample assayed by Prof. Charles E. Munroe contained 17.5 ounces of gold and 12 ounces of silver per ton, no free gold being visible. Pyrrhotite impregnates the country rock in the vicinity, and bronze-colored slickensides of it are seen along the vein.

THE BADGER HILL VEIN.

The Badger Hill vein, on the South Fork of Wolf Creek, 2,000 feet southwest of the Crown Point, does not crop plainly on the surface; it is said to dip to the north under the railroad; no work has been done on it for a long time. The shaft is said to be 500 feet deep, with extensive drifts; the vein spotted, but in places carrying very rich specimens.

Within this area occupied by the veins of the Idaho system there are very few veins with a north-south strike. The Morehouse, 2,000 feet west of the Maryland, dips E. 36°; it has not been shown to contain much of value. The Washington vein, 1¼ miles above the Maryland, on Wolf Creek, has been opened to a depth of about 300 feet, and is said to "show well in sulphurets and contain 3 to 4 feet of quartz."[1]

THE IMPERIAL VEINS.

About 2 miles north-northwest of Grass Valley, on both sides of Deer Creek, there is a series of strong veins with a west-northwest strike, and closely parallel to the Idaho and Orleans veins. The veins are inclosed in gabbro or in serpentine. The principal one is the Imperial, cropping in light-colored coarse gabbro on the north bank of Deer Creek. Work on this mine was prosecuted in 1883 and 1884,

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[1] Mint Report, 1881.

when a shaft 280 feet deep on the incline was sunk and drifts extended east and west 350 feet. The vein is from 3 to 8 feet wide, showing some galena and free gold. This vein continues, with a slightly more northwesterly strike, toward Newtown.

THE VEINS OF GOLD HILL, MASSACHUSETTS HILL, AND VICINITY.

The veins in this locality, within the city limits of Grass Valley or a short distance to the southwest of them, were the earliest worked in this district, though but little work has been done on them in recent years. They are, in general, characterized by small width but rich ore, with frequently coarse gold. The sulphurets are subordinate both in quantity and quality. The strike is to the north, with variations to the east and west; the dip at angles of 20° to 40° either to the east or to the west. The veins lie either in granodiorite, porphyrite, or diabase, the latter two rocks being connected by transition. A strong sheeting of the country rock is sometimes apparent, as, for instance, in the western part of Main street, where the joints of the granodiorite dip to the west at 30°; this is illustrated in Pl. III, p. 104. Near the Larimer mine, on Wolf Creek, a strong sheeting, dipping 15° E., is developed in the diabase. The fissures of the veins are without doubt closely related to this sheeting and produced by the same force.

THE GOLD HILL-ROCKY BAR VEIN.

Located earliest of all the veins in this district, this vein has been worked extensively, though to no great depth, along a distance of 3,000 feet. The northern part has been opened by a number of vertical shafts to a depth of 100 to 200 feet. This northern part of the vein was worked nearly continuously from 1850 up to 1867, and is thought to have yielded $4,000,000 during that time. Between 1890 and 1893 the mine was opened again from the Gold Hill shaft, 550 feet deep on the incline, the vein dipping 28° E. Levels are turned at 290 and 540 feet, the lower extending 350 feet north and 500 feet south. It is expected that the mine will soon be reopened.

The vein crops in diabase, but all the lower workings are said to be in granodiorite. The strike of the vein, though very irregular, is north and south, and the dip 28° E. The upper portion, near the croppings, is, however, in places much flatter, and the whole hill slope is completely honeycombed by drifts and shafts. The Gold Hill vein is very irregular in width, varying from a mere seam up to 6 feet, the average being said to be 2 feet. At 275 feet south of the shaft the vein is said to have been cut off by a fault fissure, striking northwest and containing no ore. The hanging wall of the Gold Hill is strongly impregnated with pyrite. The vein is characterized by irregular pay shoots, at places being almost entirely barren, while in other places large pockets of coarse gold occur.[1] North of the Gold Hill shaft the

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[1] Melville Attwood, Tenth Ann. Rept. State Mineralogist.

vein is said to split, one branch extending north and the other northeast. It is impossible to verify this at present, the outcrops not being recognizable. The gold is from 850 to 870 fine.

The Massachusetts Hill vein, worked by the old Rocky Bar deep shaft, is, beyond much doubt, on the same fissure as the Gold Hill. It was worked with short interruptions between 1850 and 1866. In 1864 and 1865 1,000 tons of ore per month were extracted for a long time, and this part of the vein is reported to have yielded $3,000,000, which, if the reports are reliable, would make $7,000,000 for the whole vein. The Rocky Bar shaft was sunk perpendicularly to strike the vein, and then followed the dip of the latter; a total perpendicular depth of 300 feet was attained. An aggregate of 2 miles of drifts is said to have been run from the shaft. In 1895, after a long period of quiescence, the vein was again opened up by a shaft in the same locality. There is but little information available as to the character of the ore and pay shoots. The latter are, however, reported to be more regular than on the Gold Hill vein. The vein crops in diabase, and only that rock has been struck in the deepest workings, as attested by the dumps, but eventually it will be found to enter the granodiorite. The gold is 855 fine.

THE SHANGHAI VEINS.

The two Shanghai veins lie from 200 to 400 feet west of the Rocky Bar, and have been opened by small perpendicular shafts. A considerable amount of rich ore has been taken from them. The gold is 860 fine.

THE BLACK LEDGE.

This vein, traceable on the surface by shafts and prospect holes, begins a short distance south of the Shanghai veins and dips to the west at angles from 50° to 30°. It has been worked only to a small depth, but is said to have produced $75,000 in the early days. The Hudson Bay shaft was sunk, in 1892, to a perpendicular depth of 185 feet to intercept the vein. At 140 feet two flat stringers were found containing coarse gold, and at the junction of these stringers with the main vein the quartz was also rich. Some of the gold occurs as big leaves inclosed in a brown opal. The main ledge is wavy and irregular in strike; the narrow pay shoots dip to the south on the plane of the vein.

THE CINCINNATI HILL, SCOTIA, AND TWILIGHT CLAIMS.

The Cincinnati Hill is also a parallel vein lying half a mile west of the Gold Hill. It has been worked on a small scale off and on since 1850, and the principal explorations were made at the north end. The Scotia shaft was sunk in 1881 on a small vein to a depth of 300 feet, but nothing of value was found. On the Twilight claim several small veins are found, dipping east, parallel to the Rocky Bar. There are also in this vicinity several veins with a northerly to north-northeasterly strike and westerly dip.

THE PEABODY VEIN.

Located just outside the city limits, this vein, whose outcrops can not now be traced on the surface, has been worked at various times, the last time from 1890 to 1893. The northern shaft, which is the deepest, has been sunk 400 feet on the incline; the upper levels are connected with the old shaft. The vein, which dips 33° W., lies partly in granodiorite, partly in uralite-diabase. The width is said to be 18 inches on the average. The quartz of the vein contains extremely heavy and coarse gold in irregular shoots.

THE JERSEY BLUE AND HERMOSA VEINS.

These veins, located near the Watt Park, strike to the northeast and dip northwest at angles from 20° to 35°, the country rock being uralite-diabase. The latter mine is opened by a shaft 600 feet deep on the incline. The vein is said to be from 2 to 2½ feet in width, and the quartz contains some pyrite and galena. The work was chiefly done in 1892. In the following year the mine was shut down, the ore shoots not having come up to expectations.

THE DROMEDARY-GRANITE HILL VEIN.

This long vein crops in granodiorite on the east side of Wolf Creek, chiefly within the city limits, and is nearly parallel to the Gold Hill vein, though dipping in an opposite direction. The two veins will clearly intersect at no great depth. At its northerly end the vein forks, the western branch turning north-northwest through the city, and is here known as the Rock Roche vein; it is narrow, but some rich specimens are said to have been found in the croppings. South of this it is known as the Dromedary, and has been worked at various times. The vein was worked in the early fifties; again in 1863 good ore was taken out; from 1868 to 1873 it was worked with varying success by the Dromedary Company, which erected pumping and hoisting works and a 10-stamp mill. The vein is said to be from 1 to 4 feet wide, and has furnished considerable quantities of ore containing coarse gold and running from $30 to $60 per ton. The next claim is known as the Wyoming, on which in recent years a shaft has been sunk 280 feet on the incline and some high-grade ore extracted. The sulphurets are said to be very rich, containing $300 per ton. South of the Wyoming the vein is known as the Crandall, and has been worked by means of tunnels from Wolf Creek.

South of this again is the Granite Hill mine, in all probability on the same vein. The Granite Hill is developed by a shaft 500 feet deep on the incline, with drifts extended on the third and fourth levels to a maximum distance of 200 feet. Rich ore was found along the outcrops in 1850. In 1870 the mine was worked to some extent, and again opened in 1892 and 1893. The croppings are in granodiorite, but at the third level the vein cuts across the contact into diabase without any notable change. The fourth level is entirely in diabase. A dike of granite-porphyry was noted south of the shaft on this level. The vein, which dips from 15° to 30° W., is small, sometimes closing down to a mere seam, as in the third and fourth levels south, then again opening up and containing 1 or 1½ feet of quartz. The foot wall is well defined, the hanging being more irregular. Fresh country rock often comes close to the vein. The ore in the upper levels was of a generally poor character, but in the fourth level north a pay shoot was struck, running up to a point between the fourth and third levels. The ore is high-grade, ranging up to $50 per ton. Sulphurets are very abundant, consisting chiefly of pyrite, yellow or brown zincblende, and very little galena. The gold is frequently coarse, in leaves and masses adhering to the quartz crystals, and often noted to be associated with the blende. The concentrated sulphurets are not of high grade, containing only about $60 per ton. The quartz is often crystallized, comb structure being very common, and the whole vein sometimes filled with loose bunches of milk-white crystals, often radiating from a fragment of country rock, partly replaced by pyrite. In the more compact parts of the vein druses with crystals are of common occurrence.

The Dromedary-Granite Hill vein appears to contain more sulphurets than the diabase veins.

THE ROSE HILL VEIN.

The Rose Hill vein adjoins the Dromedary on the east, but dips in the opposite direction. This vein is reported to have yielded $100,000, and a few years ago $7,000 in specimens was taken out within a small space. Recently the mine has been reopened. The shaft is 122 feet deep on the incline. The vein is from 4 to 15 inches wide.

THE VEINS IN THE VICINITY OF NEW YORK HILL AND NORTH STAR.

From the Hudson Bay shaft southward for a distance of 3,000 feet the diabase is cut by an extensive system of flat veins. The outcrops form wavy, irregular lines, and some of the veins are practically horizontal. In general the strike is east and west and the dip either to the north or, more rarely, toward the south. The veins are narrow, but frequently very rich; the pay shoots are extensive and fairly regular. The percentage of sulphurets, consisting chiefly of pyrite and galena, is small, and the gold is of unusually high value.

The red soil is deep all over this hill and the outcrops are, as a rule, only traceable by means of the old pits and shafts. On account of the flat dip of the veins vertical shafts have here been extensively used for exploitation.

THE EMMET AND IRISH AMERICAN VEINS.

The croppings of these extend in curved lines a short distance south of the Hudson Bay shaft. The Emmet dips south at 45° and the Irish American to the northeast at 35°. The Granger shaft, sunk to a depth of 200 feet perpendicularly, intersects the Emmet in the bottom, having penetrated the Irish American above.

THE NEW YORK HILL VEIN.

This vein extends with irregular outcrops southeast from the Chevanne shaft, passing south of the New York Hill shaft, where the surface croppings are strong, and thence, largely due to the steep slope of the hill, pursues an easterly direction and is believed to extend down to Wolf Creek. The strike is on the whole west-northwesterly, and the vein belongs without much doubt to the North Star system of east-west veins. The vein has been worked from the Chevanne shaft 550 feet deep on the incline, as shown by Pl. XXII, but the principal work has been done on the New York Hill ground. Located very early, the New York Hill is estimated to have produced $500,000 between 1852 and 1865. In 1866 and 1867 the mine produced $106,430 from 2,189 tons, yielding $49 per ton. The mine was then closed for several years, until 1874, when it was opened by means of a tunnel from Wolf Creek. From September, 1874, to October, 1875, the mine produced $100,000, the yield being at the rate of from $28 to $49 per ton. It is to be regretted that no maps are available illustrating the occurrence of these rich ore bodies. The mine was in successful operation up to 1883, at which time the shaft was opened to a depth of 1,300 feet on the incline, and 13 levels turned, with drifts from 100 to 1,000 feet long. The average of the ore in 1882 is given as $25 per ton. The mine shut down about 1885 and has since remained idle.

The vein is from 8 inches to 2 feet wide, encased in hard rock; the dip of the shaft is 33° NE. The percentage of sulphurets varies from 2 to 3, and the value between $80 and $100. Coarse specimen gold is of frequent occurrence.

THE NEW ROCKY BAR VEIN.

The workings on this interesting vein are fully shown on Pl. XXII, the mine having been in operation between 1880 and 1885. The sections show the existence of two flat veins dipping north and south and meeting in a curved anticlinal. A better illustration of the contemporaneous character of the two fissure systems could hardly be obtained. The New Rocky Bar produced large quantities of extremely coarse gold in 1880 and 1882, much of it being sold for the manufacture of jewelry. No data are available as to the production. The very flat "top vein" shown in the section has been worked through numerous small perpendicular shafts, and found in places to be very productive in coarse gold.

THE BOWERY VEIN.

A shaft a few hundred feet deep has been sunk on this vein, which is parallel to the North Star, and outcrops 600 feet north of it. The shaft is 900 feet east-northeast of the North Star shaft. The vein is credited with a production of $3,700 in 1869 (Raymond's reports), and about 1866 300 tons were extracted, yielding $15 per ton. The vein averages 20 inches wide (Bean's Directory).

THE INKERMAN VEIN.

This deposit, which extends a short distance south of the North Star, is not developed to any extent. It was opened in 1865 by a vertical shaft 60 feet deep and a tunnel 400 feet long; the vein, which averages 12 inches in width, has produced some beautiful specimens (Bean's Directory).

THE LAMARQUE VEIN.

The Lamarque lies about 600 feet south of the North Star and dips to the south. The vein was worked with profit for several years, but has been idle lately, until in the end of 1894, when it was opened again and yielded some ore averaging $20 per ton.[1]

THE NORTH STAR VEIN.

History.—The North Star vein, one of the most celebrated of the Grass Valley deposits, was discovered in 1851, and worked to some extent up to 1857, yielding $250,000, according to Bean's Directory. It was known in early days as the Helvetia and Lafayette, and Blake describes it under this name in 1853. In 1860 the name was changed to North Star, and it was extensively worked up to 1874, when it was shut down and believed to be worked out. During this period it produced a large amount, frequently hoisting 600 tons per month. In 1866 it yielded at the rate of $24,000 per month; in 1869 it produced $330,000; in 1870, $167,400; in 1873, $150,000; and the total product, 1860 to 1874, is probably not less than $2,500,000. After ten years of quiescence the mine was reopened, in 1884, and it has been worked continuously since. In the continuation of the shoot richer ore was met with than in the upper levels, and the production for the last years has been as follows: 1889, $413,200; 1890, $196,300; 1891, $266,000; 1892, $235,400; 1893, $335,760. The production for the last ten years amounts to between $2,000,000 and $2,500,000. The total production of the vein is thus not less than $5,000,000. In 1894, owing to reasons explained below, there was a great decrease in the production, and the mine has in the last year worked chiefly remaining ore bodies in the upper levels.

Developments.—The shaft, following the vein on the incline, has attained a length of 2,400 feet, with a vertical depth of 840 feet. The extent of the levels, as well as the direction of the shaft, is shown on Pl. XXIII. There is a 40-stamp mill on the property.

Country rock.—The vein is inclosed in a dark-green, fine-grained rock of often chloritic aspect. It is in places porphyritic by the development of small feldspar crystals, and ranges in composition from a uralite-diabase to a uralite-porphyrite, the augite being rarely preserved. Grains of pyrite, pyrrhotite, and copper pyrite occur in the rock. Only toward the west is there any indication of change in

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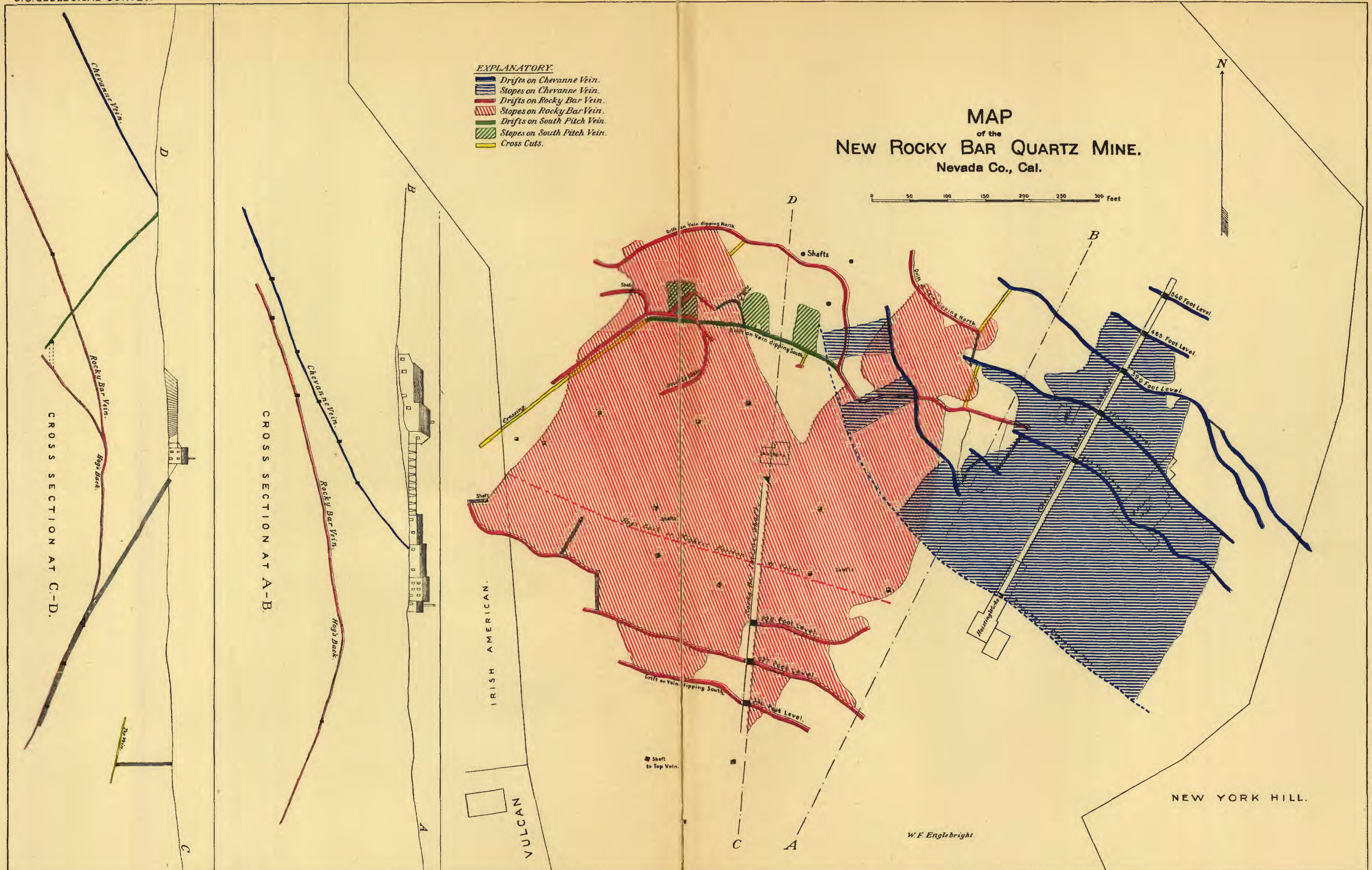
[1] Nevada County Mining Review.


MAP
of the
NEW ROCKY BAR QUARTZ MINE.
Nevada Co., Cal.
EXPLANATORY.
Drifts on Chevanne Vein.
Stopes on Chevanne Vein.
Drifts on Rocky Bar Vein.
Stopes on Rocky Bar Vein.
Drifts on South Pitch Vein.
Stopes on South Pitch Vein.
Cross Cuts.
0 50 100 150 200 250 300 Feet
N
CROSS SECTION AT C-D.
CROSS SECTION AT A-B.
Chevanne Vein.
Rocky Bar Vein.
Hog's Back.
Shafts
640 Foot Level.
465 Foot Level.
390 Foot Level.
Crossing
Shaft
IRISH AMERICAN.
VULCAN
NEW YORK HILL.
Shaft to Top Vein.
A
B
C
D
W. F. Englebright.

the country rock, as more fully explained below. The outcrops of the vein can be traced by means of the numerous little shafts on the hill to the east of the mine, for a distance of one-fourth of a mile. In the eastern part of the outcrops there are indications of a parallel vein, which is said to join the main vein at a depth of a few hundred feet.

As shown by the levels, the general strike of the vein is from west-northwest to northwest, but with many local irregularities. The dip is shown by the profile on the plate, and will average 20°, varying from 15° to 45°. The structure of the vein is well illustrated by the excellent photographs taken by Mr. E. A. Abadie, superintendent of the mine (Pls. XIII and XIV). The vein usually shows well-defined, smooth hanging and foot walls, 3 to 4 feet apart. The space between these walls is rarely if ever completely filled with quartz; a large part of it is occupied by crushed and altered country rock, and a quartz vein may lie at the hanging wall (as in Pl. XIII), in the foot wall, or, in fact, at any place between the walls. The width of the quartz does not average more than 1 foot. In places, as illustrated by Pl. XIV, the space between the walls may be practically occupied by a breccia of quartz and altered country rock. In many places within the pay shoot the walls close down to a mere seam, as, for instance, on the 2,000-foot level. Outside of the walls the diabase is but little altered by vein solution, and is often fresh and hard up to the vein. The crushed rock within the walls is greatly altered, as a rule being impregnated with pyrite and to a great extent replaced by carbonates and sericite, as shown by analysis and description on pages 149, 152. The rock below the quartz vein in Pl. XIII is entirely similar to the specimen analyzed, and the great number of veinlets shown by the photograph in the rock are all filled with carbonates, though no carbonate is contained in the main vein. A striation, horizontal or dipping slightly west, is frequently noticed on the walls. Banded structure of the quartz by arrangement of the sulphurets, as well as a sheeting due to subsequent dislocation, is quite common. Frequently, however, the quartz is massive and the sulphurets are irregularly distributed. Comb structure is apparently rare.

The ore.—The pay is almost exclusively contained in the massive quartz with sulphurets. The altered country rock between the walls contains up to a few dollars' worth of gold and is occasionally milled. The concentrated pyrite in the altered country rock contains only $15 in gold. The quartz in the pay shoot, nearly all being good ore, contains from $15 to $50 per ton, with but very little silver. Coarse gold in leafs or in bands through the quartz parallel to the walls occurs in places. The gold is unusually fine, reaching 850. The average yield previous to 1875 was $20, and between 1884 and 1894 the quartz seems to have had a higher average grade. The quartz from the cropping was very rich, and Professor Blake records in 1853 that much coarse gold occurred, and that 130 tons of quartz milled $92 per ton. The quartz contains about 2⅝ per cent of sulphurets, consisting chiefly of pyrite with a little galena and hardly anything else. (For analysis, see p. 128.) The concentrated sulphurets run from $60 up to $120, and contain silver in the ratio of 0.40 ounce to 1 ounce gold. The value of the concentrates varies with the richness of the ore.

Ore shoot.—The extent of the ore shoot is well shown on Pl. XXIII, and it will be noticed that it dips to the west on the plane of the vein. Of course the whole area explored has not been equally productive, the richest portion probably being that below the twelfth level, and some levels are entirely unproductive, but considered as a whole the ore shoot is indicated by the workings.

Faults.—According to Mr. Abadie, a cross seam, striking northeast and dipping steep toward the southeast, faults the vein considerably on the seventeenth level; above this the faulting is said not to be noticeable. The fault continues, though with smaller throw, on the lower levels; on the twenty-first level it is very distinct, and the throw amounts to 16 to 18 feet along the hade of the fault. The cross seam, which does not carry any quartz, would intersect the shaft a little below the twenty-fourth level. To the west of the shaft the pay shoot has been found to end abruptly along a vertical plane laid almost due north through the collar of the shaft, and it has been supposed that the vein has been cut off by a fault, usually referred to as a crossing. There appears to be some difficulty about the proper interpretation of the facts at this place. In the eighteenth level there are, indeed, several planes, striking north and dipping about 50° W., which intersect the vein, and on the main one a horizontal striation appears. Before reaching this plane the vein splits; immediately at the plane there is no direct evidence of any great fault. West of the "crossing" the vein is replaced by a single seam without quartz; this was followed for some distance, and finally cross cuts started in hanging and foot walls. In the hanging more solid rock was met, but in the foot wall there was found a series of seams all dipping north in the crushed and altered diabase. It appears very much as if the vein along the line of the crossing had split up into a series of stringers and seams.

On the surface a short distance west of the shaft the sedimentary rocks appear, the contact running north; these clay-slates and cherts had not, at the time of my visits to the mine, been encountered in the eighteenth level, from which it follows that the contact must dip west parallel to the cross seam mentioned. It is very likely that the change in formation a short distance westward may, as Mr. H. C. Hoover thinks,[1] have caused the breaking up of the vein. The vein may appear again to the west, though the sedimentary rocks are less favorable than the diabase for a well-defined fissure; or a continuation of the pay shoot may be found in depth, the latter alternative having more probability.

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[1] Mining and Scientific Press, March, 1896.

THE CENTRAL NORTH STAR.

Considerable prospecting has been done toward the east to find the continuation of the North Star vein, and two shafts, indicated on the map, were sunk on the Central North Star claim. The upper shaft, 200 feet deep, struck at that depth a pretty large barren vein dipping north. The lower shaft is started at an angle of 52° from the horizontal and in a direction N. 35° W., following down a crushed zone with pyritic impregnation, but no quartz. At 400 feet a vein was struck, dipping 35° NE., and striking northwest. The rock, a normal diabase, is hard and fresh close to the vein. This vein, which is up to 1 foot wide, shows in places good prospects. It is of course difficult to decide whether these veins really are the continuation of the North Star fissure.

THE OMAHA SYSTEM.

Beginning at the Omaha mine and extending down the west side of Wolf Creek for over a mile is a series of parallel veins having many common features. They all dip to the west at moderate angles; all of them are inclosed in granodiorite; and most, if not all of them, are distinguished by rather abundant sulphurets and a percentage of silver in the sulphurets in excess of the usual amount.

THE OMAHA VEIN.

This vein is the most prominent in the system and is traceable for a distance of 4,500 feet, the most northerly outcrops appearing on the east side of Wolf Creek a short distance north of the Omaha mine, and the most southerly a short distance east of the Surprise shaft.

The Omaha and Lone Jack mines.—The Omaha and Lone Jack mines, worked by the same company, have for many years been heavy producers. The Lone Jack, located in 1855, had in 1867 a shaft 600 feet deep on the incline and was reported to have produced $500,000. The chief work on these mines was begun about 1875, and in the last years they have been steady producers. The total output is said to reach $2,000,000,[1] and in the mint reports from 1889 to 1892 they are credited with from $105,000 to $118,000. The Omaha shaft has attained a depth of 1,500 feet on the incline; the Lone Jack, located 700 feet farther south, 1,600 feet; and they are connected by drifts on most levels. There is a 28-stamp mill on the property.

The vein, which on the surface has a regular strike, develops notable curves in the strike. The dip averages 33° W. The vein forms a narrow fissure in hard granodiorite, occasionally sheeted in the vicinity of the vein. To the north of the Omaha shaft all drifts soon run into diabase. On the tenth level the diabase contact lies 20 feet south of the shaft. Diabase also appears at the shaft on the fourteenth level. Near the contact smaller dikes of white or gray, compact and flinty

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[1] Nevada County Mining Review.

granite-porphyry (quartz-porphyry) are met with. The vein is said to usually become poor when incased in this rock. The tenth level extends 1,000 feet northward, some good ore occurring in it in bunches, but farther in the vein is disturbed by crossings and shows signs of splitting up.

The vein is narrow, probably averaging 1 foot, and lies between well-defined hanging and foot walls without much inclosed altered country rock. Outside of the pay shoots the vein generally closes to a seam, so that practically all quartz is good ore. The granodiorite next to the vein is impregnated with pyrite, but on the whole is unusually fresh and hard. Calcite occurs to only a limited extent in the wall or in the vein. There is very little banded or ribbon quartz, most of it being massive, with sulphurets in irregular distribution. The ore is of high grade,

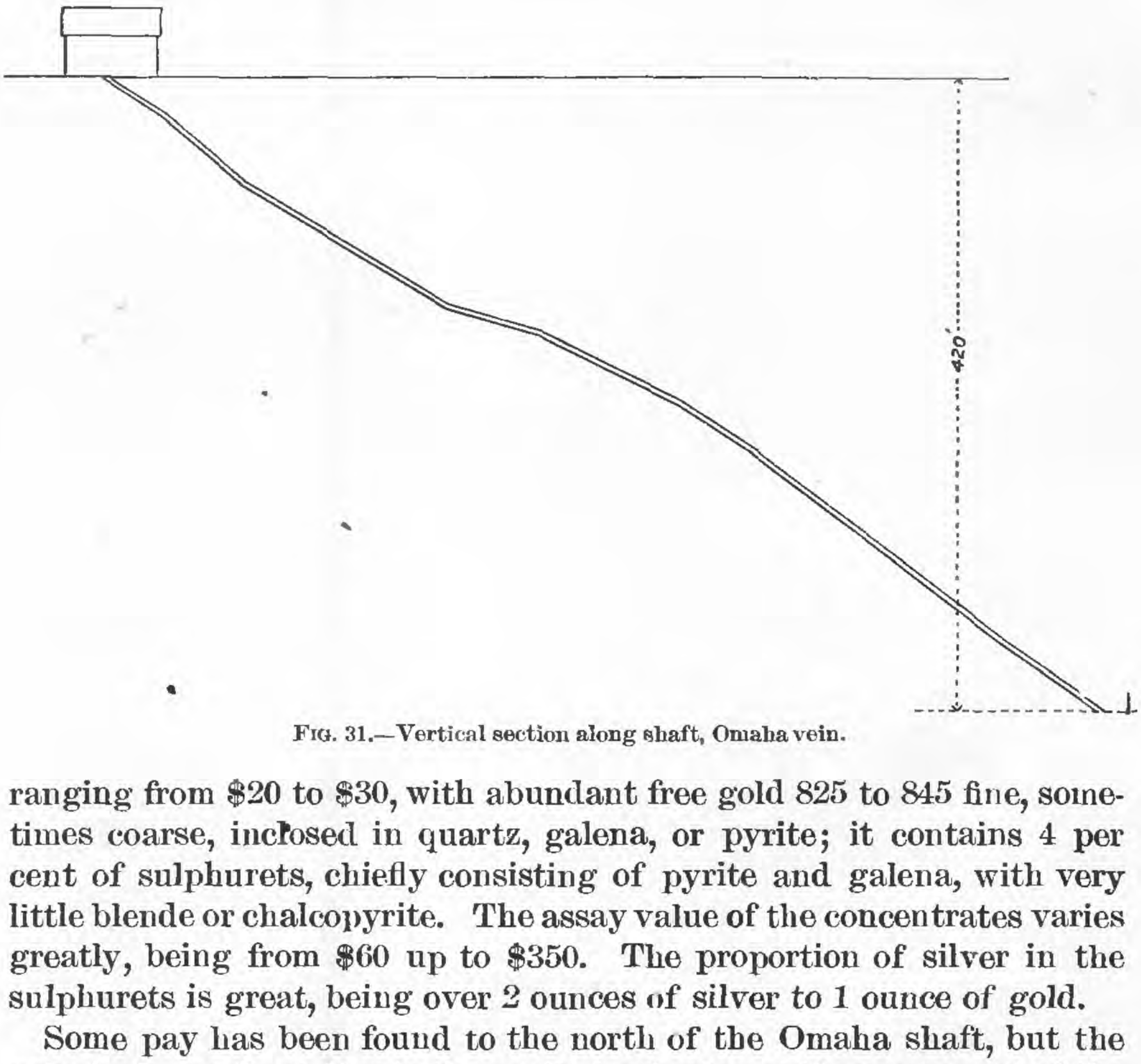

FIG. 31.—Vertical section along shaft, Omaha vein.

ranging from \$20 to \$30, with abundant free gold 825 to 845 fine, sometimes coarse, inclosed in quartz, galena, or pyrite; it contains 4 per cent of sulphurets, chiefly consisting of pyrite and galena, with very little blende or chalcopyrite. The assay value of the concentrates varies greatly, being from \$60 up to \$350. The proportion of silver in the sulphurets is great, being over 2 ounces of silver to 1 ounce of gold.

Some pay has been found to the north of the Omaha shaft, but the principal pay shoot dips to the south, beginning at the upper part of the Omaha shaft and extending toward the bottom of the Lone Jack. Very rich ore was extracted from this shoot in 1894 on the fourteenth level. Another pay shoot, also dipping south, has been found south of the Lone Jack. A strong "crossing" or barren fissure traverses the vein along the principal pay shoot, with a steep dip to the south. It does not seem to affect the tenor of the ore. On the twelfth level the vein is faulted about 1 foot by this crossing, with a relative downthrow of the south side, and on the fourteenth level the curious relation illustrated in fig. 32 obtains at the crossing, showing a differential movement of the sheets constituting the crossing. A similar cross seam, faulting and dragging the vein, is found at the end of the tenth level north.

The Homeward Bound mine lies to the south of the Lone Jack. Only superficial developments were made up to 1867, the vein having been worked along the surface for 200 feet. The shaft at present on the property has been sunk to a depth of 350 feet, the incasing rock being very hard. Two levels are turned at 165 and 268 feet from the surface, the drifts extending a maximum distance of 350 feet southward and 750 feet northward, four distinct pay shoots having been found. The vein is said to be large. The mine was worked in 1889–90.[1]

The Hartery mine has worked two parallel veins. The old shaft is sunk on the southern end of the Omaha vein to a depth of 600 feet on

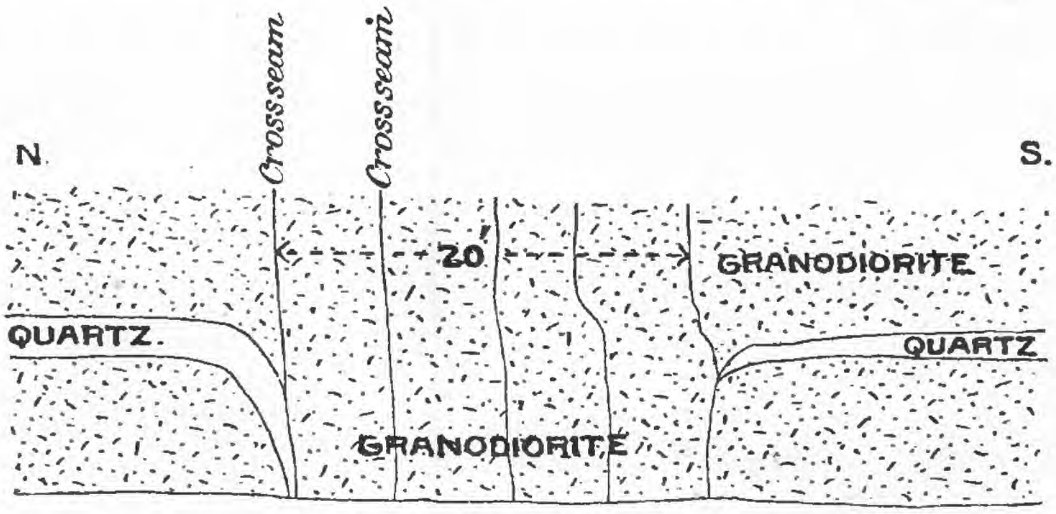

FIG. 32.—Longitudinal section, showing fault, Omaha mine, fourteenth level.

the incline. "The vein, which was located in 1853, has been worked at intervals since that time, but not more than ten or twelve years of continuous work has been spent on the property. Over $300,000 have been taken from the mine, some of the ore consisting of extremely rich specimens of coarse gold."[2] The mine was idle in 1893 and 1894. Productions ranging from $19,000 to $39,000 are credited to the mine in the United States reports for 1869, 1890, and 1891. "Three levels are turned, at 368, 508, and 600 feet, extending north a maximum distance of 300 feet and south 400 feet. A drain tunnel from Wolf Creek, 1,200 feet long, intersects the shaft 250 feet from the collar."[1]

The vein dips 30° W. and is inclosed in hard granodiorite; it averages somewhat over a foot in width. The ore is of high grade, probably averaging about $30 per ton. The amount of sulphurets is said to be small and their value $50 per ton. In the mint reports of 1890 and

[1] Tenth Ann. Rept. State Mineralogist.
[2] Nevada County Mining Review.

1891 the mine is credited with a considerable amount of silver, the relation being for the first year 1,635 ounces of gold and 871 ounces of silver.

The Hartery Consolidated shaft is sunk to a depth of 500 feet on the incline, on a parallel vein a short distance east of the Omaha vein, but comparatively little development work has been done from it. The incasing granodiorite is reported to be very hard.

THE WISCONSIN-ILLINOIS VEIN.

This is parallel to the Omaha vein, and crops a few hundred feet to the west. It was worked at its northern end from 1854 to 1856 and again from 1866 to 1870, during which time it produced a considerable amount of high-grade ore. In 1869 the old shaft was sunk to a depth of 500 feet on the incline, and the extent of the stopes is shown on fig. 33, copied from Raymond's report for 1869–70, page 47.

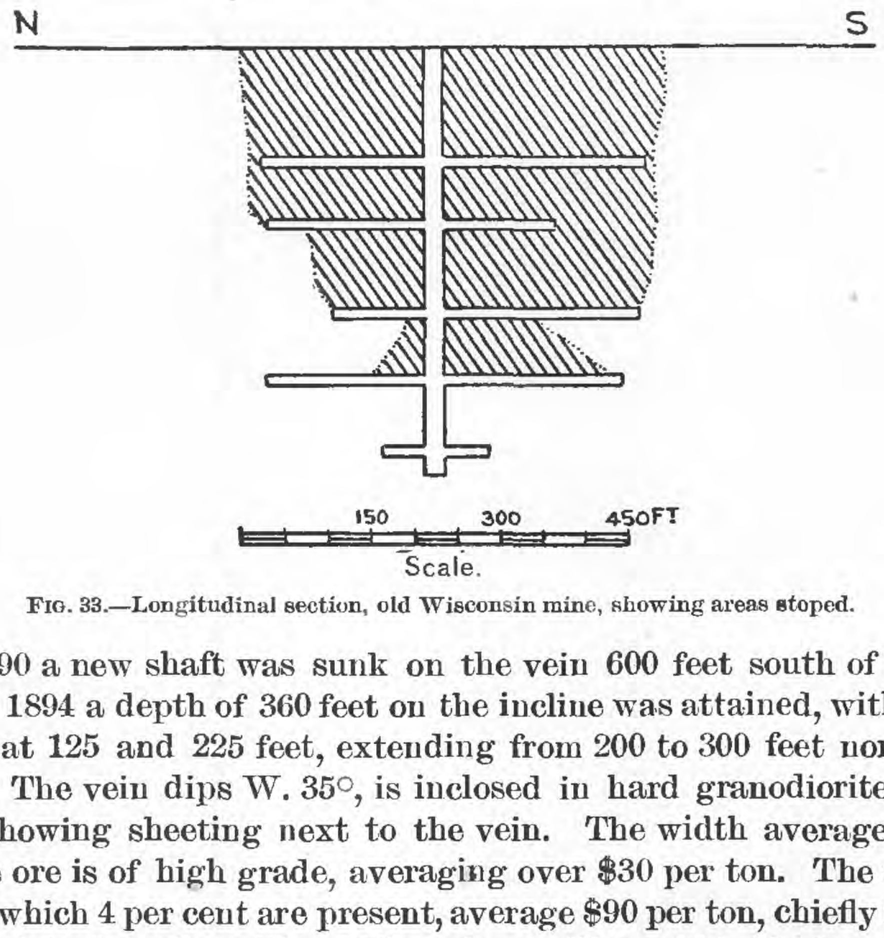

FIG. 33.—Longitudinal section, old Wisconsin mine, showing areas stoped.

In 1890 a new shaft was sunk on the vein 600 feet south of the old one; in 1894 a depth of 360 feet on the incline was attained, with levels turned at 125 and 225 feet, extending from 200 to 300 feet north and south. The vein dips W. 35°, is inclosed in hard granodiorite, sometimes showing sheeting next to the vein. The width averages 1 foot and the ore is of high grade, averaging over $30 per ton. The sulphurets, of which 4 per cent are present, average $90 per ton, chiefly in gold, and consist of pyrite, with a little galena. The gold is 854 fine. In the old shaft there was an extensive pay shoot supposed to dip to the south, and the present shaft is sunk to intercept that in depth. There are also two smaller pay shoots of high grade, one on each side of the new shaft. A cross seam cuts the new shaft without disturbing the vein perceptibly.

THE MINNESOTA VEIN.

The Minnesota vein, upon which the Surprise shaft was sunk long ago, may represent the southern continuation of the Wisconsin vein.

THE PHŒNIX-MARY ANN VEIN.

This vein, located 2,000 feet west of the Allison Ranch vein, dips west from 30° to 45°. At its southern end the Phoenix shaft has been sunk on it, from which in 1870 some ore yielding $20 per ton was extracted. The developments in the northern end of the vein are slight.

THE ALLISON RANCH VEIN.

The croppings of this vein, located about 3 miles south of Grass Valley, on the west bank of Wolf Creek, are quite inconspicuous and can not be traced either south or north of the shaft. The vein was accidentally discovered in 1854 by sluicing on the croppings. From that time up to 1866 the mine was worked continuously, producing 46,000 tons of ore, yielding $2,400,000. In 1863 the mine became poor, but the following year rich quartz was again found. The product for the three years ending December 30, 1865, was $1,000,000, and $200,000 were produced in 1866; the operations were suspended in September, 1866, and the mine has remained idle ever since. The shaft is sunk on the vein to a depth of 500 feet on the incline, the lowest level extending 220 feet north and 214 feet south. A portion of the quartz on this level was very rich, but the greater part was barren. There seems to have been no adequate reason for abandoning the mine without further exploration. The vein strikes N. 5° to 15° W., and dips 40° to 45° W. Phillips gives the width as 2½ feet, while Bean's Directory states it to have been from 14 to 18 inches in the lowest level, where the vein was in part considerably broken up. There is a clay parting on the hanging wall, while the foot wall is without any distinct clayey division from the quartz. Phillips states that the average yield on the lowest level was as good as that from the upper part of the mine. Near the surface the decomposed ore was extremely rich; Mr. Melville Attwood milled 21 tons in 1855 which yielded $370 per ton.[1] The average of the ore from the deepest levels was also high. The quartz was in places extremely rich; between these bunches some quartz was found that would hardly pay expenses. There was a considerable percentage of sulphurets, chiefly pyrite, but also galena and chalcopyrite; rich silver minerals were found in a specimen from the Allison Ranch vein (see p. 119).[2]

While the Allison Ranch can not be traced far on the surface, there appears on the hill to the south several veins striking north-south and opened by small prospect holes. There is in places considerable sheeting of the granodiorite, the sheets dipping west. Large outcrops show on top of the hill south-southwest of the Allison Ranch, and on the steep slope eastward are several small veins, showing some quartz with much pyrite.

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[1] Eighth Ann. Rept. State Mineralogist, p. 777.

[2] Notes chiefly from Bean's Directory, J. A. Phillips's Mining and Metallurgy of Gold and Silver, and Ross Browne's report for 1868.

OTHER VEINS.

Almost due north of the Allison Ranch shaft, a distance of 1,500 feet, is the Franklin vein, on which in early days considerable work was done and a large mill once erected.

The Allison Ranch Ford–Horseshoe vein is located on the west bank of Wolf Creek and probably is a continuation of the Franklin or an adjoining parallel vein. The Horseshoe shaft is 3,500 feet north of the Allison Ranch and 240 feet deep on the incline. The vein is from 10 to 20 inches thick.

THE FOREST SPRING GROUP OF MINES.

Four miles south of Grass Valley and 1¼ miles south of Allison Ranch there is, on the east side of Wolf Creek, a series of veins of some importance.[1] The ores are similar to those of Osborne Hill.

THE NORAMBAGUA VEIN.

The Norambagua was worked extensively between 1855 and 1867. Its total production is said to amount to $1,000,000 (Bean's Directory).

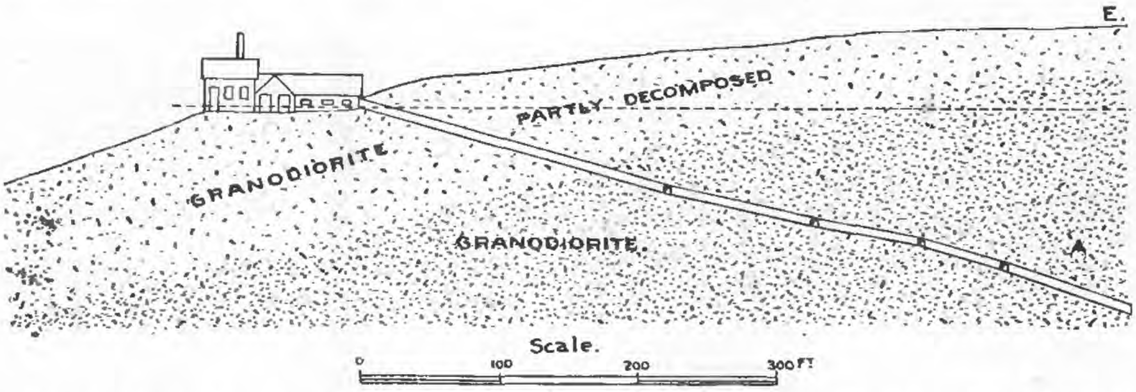

FIG. 34.—Vertical section along shaft. Norambagua vein. After Melville Attwood in Phillips's Metallurgy of Gold and Silver.

In 1866 the production was $80,000. The mine was reopened for a short time in 1892 and is credited with a production of $2,500 in that year. During the principal period of exploitation the cost of mining and milling was $30 per ton. This very high figure is evidently due to the narrow character of the vein. The incline is 567 feet long down to the fifth level, attaining a vertical depth of 120 feet at that level. The levels extend 1,000 feet south and 500 feet north from the shaft, and a drain tunnel joins the shaft 490 feet from the croppings. The Norambagua has a northerly strike and a dip of 15° E., thus belonging to another system than the Omaha. It is contained in a blocky granodiorite and is very narrow, rarely over 10 inches wide and more frequently 4 or 5. The ore is a bluish quartz, seamed and banded with pyrite and arsenopyrite arranged in parallel zones, producing a ribbon-like structure. The gold is rarely visible to the naked eye. The tenor of the ore is from $40 to $100 per ton, and frequently about $65 per ton (Phillips).

[1] See Geologic Atlas of the United States, folio No. 18, Smartsville, Cal.

There are 1.33 per cent of sulphurets, according to Phillips. Bean's Directory gives 3 per cent. These are rather low grade, being said to average $50.

The Bourbon veins lie 500 feet west of the Norambagua, and the Shamrock 1,200 feet southeast of it.

THE PERRIN OR SLATE LEDGE VEIN.

For many years this vein has been worked intermittently and has been a considerable producer. In the reports it is credited with $32,000 in 1869, $5,000 in 1890, and $13,100 in 1891. It was actively worked in 1893 and 1894. The vein is opened by an incline shaft started in the tunnel from Wolf Creek, 900 feet from its mouth, the total length of the tunnel being 1,800 feet. The incline is sunk 300 feet on the vein, which strikes east and west and dips 30° S. The country rock is chiefly diabase with some clay-slate, but the vein crosses the granodiorite contact 1,600 feet from the mouth of the tunnel. The ore ranges from $15 to $20 per ton, the gold rarely being coarse and averaging 745 fine. The sulphurets, of which there are 3 per cent, consist chiefly of arsenopyrite and contain about 3.25 ounces of gold to 2 ounces of silver per ton. On the tunnel level the pay shoot is continuous for 1,000 feet, and large quantities of ore have been stoped above it. Below the tunnel level the shoot appears to split into several branches inclining to the west, contrary to the usual rule for veins dipping south.

VEIN SYSTEMS OF PENNSYLVANIA, W. Y. O. D., AND THE WESTERN FOOT OF OSBORNE HILL.

GENERAL FEATURES.

The hills to the southeast of Grass Valley, usually referred to as the Kate Hayes and Ophir hills, are in an unusual degree shattered by jointing or sheeting, and numerous quartz veins are found parallel to these systems of dislocation. The most prominent vein system dips west at moderate angles, but there is also ample evidence of the existence of another system dipping east at about the same inclination, and there is excellent evidence of the contemporaneous formation of the two systems. The veins dipping east are best represented in the continuation of the system to the south-southeast near the southern limit of the sheet. The deposits lie chiefly in granodiorite, near the contact, while some of them are contained in the diabase. The gold is generally of high value, often coarse; the sulphurets are moderate in quantity; arsenopyrite is not generally present.

Exceptional veins are the nearly perpendicular Golden Treasure, striking north-northeast, and the Little Diamond, which dips 45° S.

KATE HAYES VEIN.

Located on the summit of Kate Hayes Hill, 4,000 feet south of the Grass Valley post-office, this vein was worked considerably thirty years ago, as is indicated by the pits along the croppings. The total production is said to have been $125,000, and the ore contained from $35 to $50 per ton.[1] On the summit of the hill is a shaft 300 feet deep on the incline, on which work was resumed in 1895 under the name of Hecla mine. The vein dips 45° W. and is inclosed in hard granodiorite.

THE CRESCENT VEIN.

The Crescent vein is located 600 feet east of the Kate Hayes, and dips to the east.

THE PENNSYLVANIA VEIN.

A few hundred feet farther west the Pennsylvania vein is met with. The vein has been exploited at various times and produced a large total amount. Work of development has been going on for the last five years, and in 1894–95 a considerable amount was produced.

The vein, which is inclosed in granodiorite, can be traced on the sur-

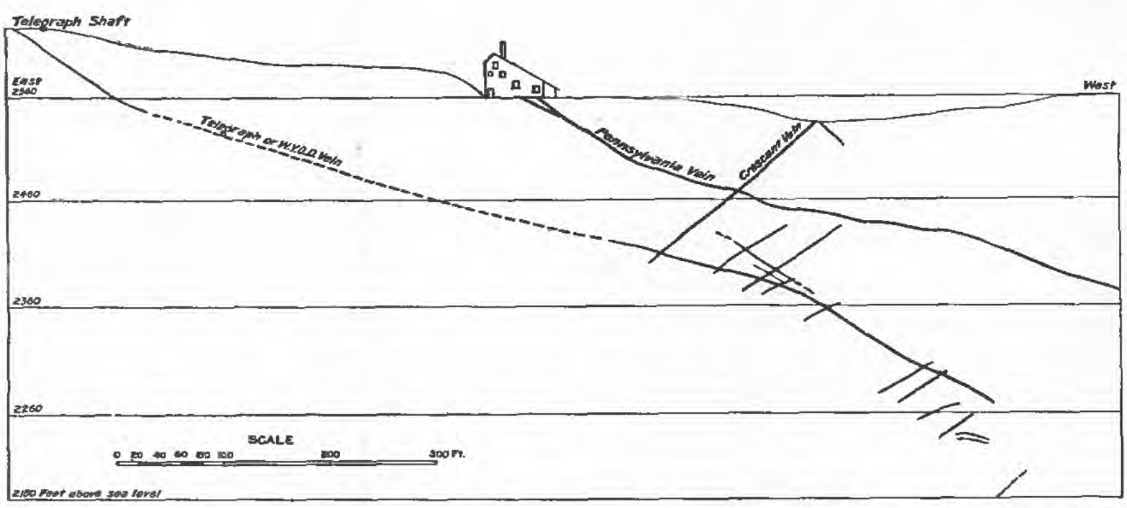

FIG. 35.—Vertical section along shaft, showing veins and cross fissures, in the Pennsylvania mine.

face for 1,000 feet north of the shaft, while to the south the continuity of the surface croppings is doubtful. The shaft is sunk to a depth of 600 feet on the incline, the vein dipping west at an average angle of 20°. A part of the shaft, continued down at a steeper angle, struck a parallel vein believed to be the Telegraph, though this would necessitate a a very flat dip for the latter. The vein averages a little less than 1 foot in width; the ore carries frequently coarse gold and a small percentage of pyrite and galena. The wall rock is generally fresh, or at least not extensively altered. The sheeting and fracturing are very extensive and render the work of exploitation very difficult; the vein frequently pinches to a mere seam, difficult to follow. The system of fissures dipping east is very prominent; at 220 feet on the incline the Crescent vein intersects the Pennsylvania, and throughout the mine there is a constant tendency of the main vein to throw out stringers dipping east. These relations are illustrated in fig. 35. Besides, there

[1] Nevada County Mining Review.

is a system of "crossings" or barren seams striking northeast, usually dipping southeast at steep angles. Most of these crossings appear south of the shaft, and at least one of them throws the vein on the fourth level 90 feet (measured along the drift) in the foot wall—that is, produces a normal fault with a relative downthrow of the south side. The crossings contain no quartz and afford excellent conduits for the subterranean circulation of water.

The largest ore bodies were found north of the shaft between the first and third levels. The ore body then appeared to be cut off, but the apex of a new shoot was found on the fourth level south of the shaft. On the whole, the ore shoot thus dips to the south on the plane of the vein.

THE W. Y. O. D. VEIN.

Only in the last few years has this vein entered the ranks of the large producers. Long known on the surface as a small 3 to 6 inch vein, it rapidly developed strength as depth was attained. The production for the four years from 1890 to 1893 was, respectively, $26,000, $53,500, $108,700, and $143,360. The shaft is at present 1,400 feet deep on the incline, drifts extending a maximum distance of 700 feet south and 600 feet north.

The vein, which dips 32° W., can be traced in the granodiorite up to the Telegraph mine, where a small shaft 175 feet deep on the incline was sunk on it in 1892. South of the W. Y. O. D. it enters the diabase and turns more southeasterly, the vein at the same time attaining a steeper dip. In Little Wolf Creek the exposures are not satisfactory, but the vein cropping on the ridge to the south of it and opened by a tunnel 700 feet long, indicated on the map on the south side of the ridge 2,500 feet south of W. Y. O. D. mine, may be the continuation of this vein. In the tunnel this vein is nearly perpendicular and 2 feet wide. The relation of the granodiorite contact on the surface and on the plane of the vein is shown in fig. 36, accentuating the wholly irregular surface separating the two formations. On the eleventh level the contact was crossed, and the deepest parts of the mine are now in granodiorite. The contact is generally sharp; in places light-colored granite-porphyry (quartz-porphyry) is met with near the contact.

The vein is generally narrow, occasionally reaching 2 feet in width, and sometimes closing down to a seam. A little calcite sometimes occurs close to the vein in the country rock, which is much fractured and impregnated with pyrite. Cavities filled with quartz crystals are common on the vein. The ore consists of quartz with finely distributed gold, 806 to 832 fine. The sulphurets, of which there are 2 per cent, consist of pyrite, galena, and blende, with a little arsenopyrite in places. The sulphurets contain from 2.5 to 4.5 ounces of gold and 5 to 8 ounces of silver per ton, the richest being the galena from the fine slimes. The sulphurets from the altered country rock adjoining the vein contain only from $6 to $12 per ton. The general tenor of the ore is high, ranging from $20 to $50 per ton. The ore shoot, which was narrow in the upper part of the mine, rapidly widened between the sixth and ninth levels, attaining a maximum length of 850 feet; below this it showed a lower grade of ore for some distance, and then improved again greatly. The shoot, though very irregular in its details, dips on the whole to the south on the plane of the vein. Thus far the largest ore bodies have been found in the diabase. There are a number of seams dipping east, as in the Pennsylvania, and there is a tendency of the vein to fall back in the foot wall on these seams. A great number of "crossings," or barren seams, follow the ore shoot down, with a general southwesterly strike and steep or vertical dip; they do not appear to throw the vein to any noticeable extent.

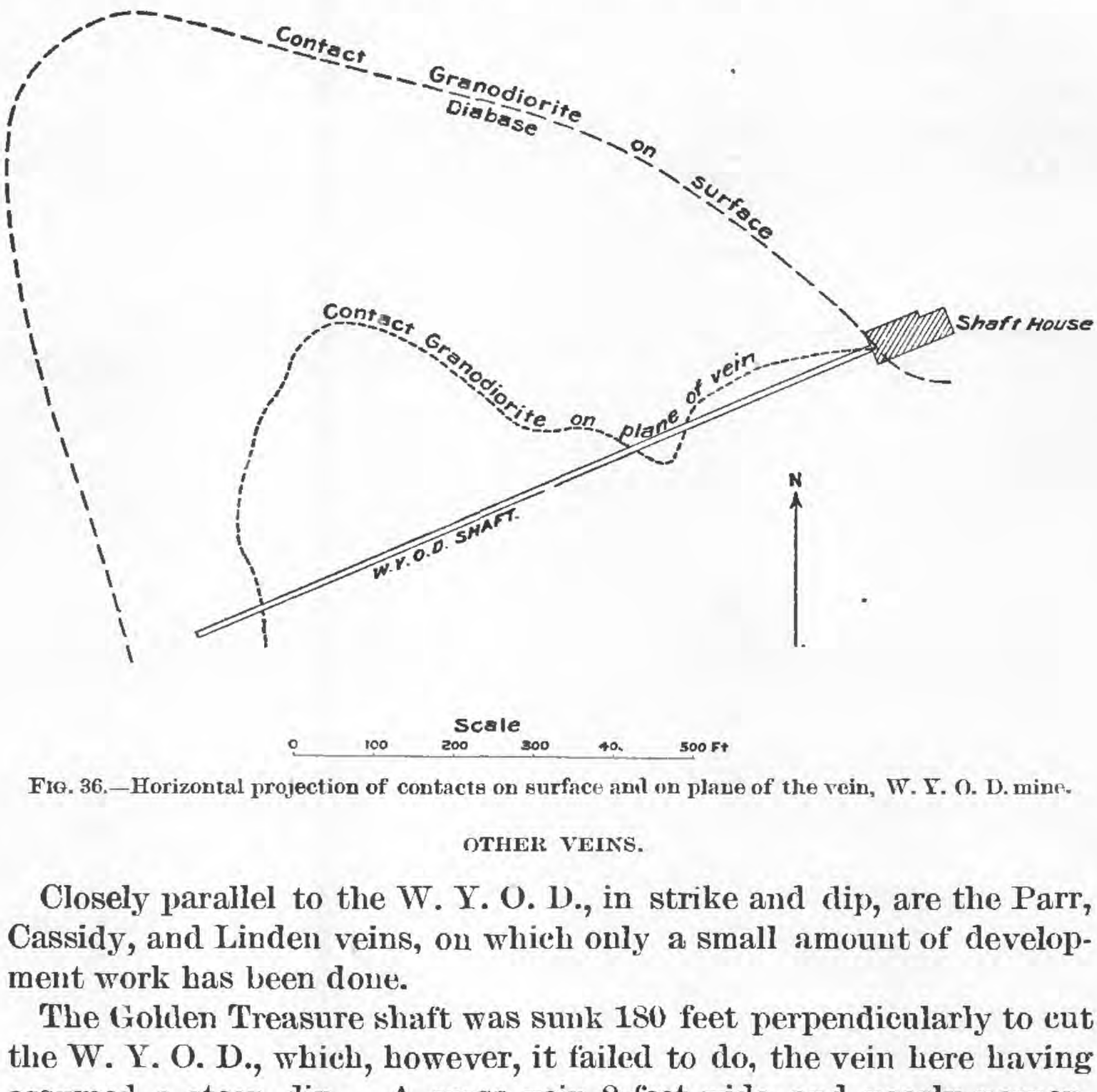

FIG. 36.—Horizontal projection of contacts on surface and on plane of the vein, W. Y. O. D. mine.

OTHER VEINS.

Closely parallel to the W. Y. O. D., in strike and dip, are the Parr, Cassidy, and Linden veins, on which only a small amount of development work has been done.

The Golden Treasure shaft was sunk 180 feet perpendicularly to cut the W. Y. O. D., which, however, it failed to do, the vein here having assumed a steep dip. A cross vein 2 feet wide, and nearly perpendicular, outcrops just west of the shaft.

THE DIAMOND, BULLION, AND ALASKA VEINS.

Following the western foot of Osborne Hill, there are a number of veins with an easterly dip of about 45°. It is very likely that they may in reality be one continuous vein with a general north-northwest strike, but the outcrops can not be continuously followed. The Big Diamond vein outcrops for a few hundred feet 3,000 feet due east of the Omaha mine. It has been opened by a tunnel and small shaft, and in former years (1869 to 1872) a considerable amount of ore, averaging $20 or more per ton, has been extracted from it. The vein is said to be 2 feet wide.

The Little Diamond is a cross vein dipping 48° S. and containing a shoot of ore dipping to the west on the plane of the vein. It is opened by a shaft 290 feet deep on the incline, but no work has been done on it in recent years.

The Galena and Bullion vein was worked at its northern end, known as the Ione or Galena, in 1865, by a vertical shaft 140 feet deep. The vein is 1 to 4 feet thick, the ore averaging $20 (Bean's Directory). The gold is 815 fine. On the southern part the Bullion shaft (formerly known as the "Union Jack") has been sunk to 400 feet perpendicularly, with drifts aggregating 500 or 600 feet. The production is reported to be $500,000, the width 1 to 4 feet, and the ore to contain $8 to $50 per ton. It has been idle for a long time.[1]

South of the Bullion lies the Alaska shaft, sunk 100 feet perpendicularly, then for 400 feet following the vein. South of the Alaska the vein bends to the southeast and enters the diabase area. The Lebar, or Presqu'isle, 1,500 feet south of the Alaska, belongs to the same system, and has yielded some good ore from a 1-foot vein.

THE FRANKLIN AND OTHER VEINS.

The Franklin is located east of the Alaska, higher up on the hill; it has been worked intermittently by means of tunnels and a small incline, and yielded a considerable aggregate sum. The vein lies chiefly in decomposed diabase, but its northern end cuts into the granodiorite. The dip is 35° W. The ore is of high grade and is rich in sulphurets, the gold being 808 fine.

In the lower part of the ravine emptying into Wolf Creek due east of the Wisconsin mine, called Little Diamond Ravine, two veins are found—the Snowpoint, opened by a tunnel 500 feet long, and the Portland, a strong vein outcropping on the side hill east of the ravine. The Portland is said to be 4 feet thick and rich in sulphurets, and has produced some ore of medium grade.

THE EMPIRE-OSBORNE HILL VEIN SYSTEM.

This complex of veins, extending for nearly 3 miles with a general direction of N. 17° W., forms an excellent example of a "Gangzug," or system of "linked veins." The veins lie throughout in diabase, diabase-porphyrite, or porphyrite-breccia. The dip is always to the west, averaging 35°. In spite of this general similarity the ores are not identical throughout. From the Orleans mine southward the eastern

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[1] Nevada County Mining Review.

part of the system contains a lower grade of gold and is particularly distinguished by a considerable percentage of arsenopyrite. There are two main branches—the Rich Hill and the Ophir Hill, the latter being the more extensive. Both join at the Magenta mine, and beyond this point appear to break up into stringers. The Magenta shaft is sunk on the vein just north of the junction to a depth of a few hundred feet on the incline. The mine was worked on a small scale at different times up to about ten years ago. "Between the second and third levels a vein known as the Mohawk intersects it at right angles."[1]

THE EMPIRE MINE.

The Empire enjoys the distinction of having been worked more nearly continuously than any other mine in the district, having been in operation with but short interruption from its discovery in 1850 to the present time. Between 1852 and 1864 it is reported to have produced $1,000,000, and from 1864 to the close of 1866 the output was $300,000. In 1866 it produced 1,200 tons per month. In 1869 the output was $349,000; in 1870, $240,000; in 1873, $240,000; in 1874, $187,000; in 1875, $232,000; in 1889, $35,500; in 1890, $73,100; in 1891, $103,000; in 1892, $82,000; in 1893, $110,800. The total production is probably in the vicinity of $6,000,000.

The Empire has a shaft 2,400 feet deep on the incline on the Ophir Hill vein, as well as a smaller shaft on the Rich Hill vein. The drifts on the main vein extend to a maximum length north 1,500 feet and south 700 feet. A 40-stamp mill reduces the ore. The vein carries a large amount of water, the cross seams carrying it down from the whole hill. The outcroppings of the vein lie entirely in a fine-grained diabase, but at or near the eleventh level the vein cuts across the contact into the granodiorite. These upper workings are not accessible now. Smaller dikes of granodiorite were noted on the fifth and seventh levels.

The vein has a northerly strike, changing in the southern part of the mine to north-northwest, with many curves and local irregularities, the dip, which is fairly regular, averaging 24° W. The vein is narrow, usually from 10 to 18 inches wide, and in structure is very similar to the North Star vein. There are usually two distinct walls, 3 to 4 feet apart, with quartz vein in the hanging or foot, or both, and seams also traversing the altered country rock separating the walls. (See Pl. XV.) Outside of the fissured zone the diabase is fresh and hard, while within it is usually extensively altered by carbonatization and traversed by seams of calcite. Occasionally small open fissures are found in it coated with calcite crystals. It is also usually impregnated with pyrite, and this replaced country rock, when found near rich quartz, may contain two or three dollars in gold per ton. Gold has been observed to occur occasionally inclosed in the decomposed country rock. The ore

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[1] Mint report, 1883.

consists of quartz with often coarse, free gold 805 fine. The quartz is partly ribboned, partly massive, and contains 3 per cent of sulphurets, chiefly pyrite, with little galena and occasionally blende and chalcopyrite. Arsenopyrite is absent. The concentrated sulphurets contain from 3.5 up to 5 ounces of gold and about 2 ounces of silver. Large parts of the pay shoot have averaged $30 to $50 per ton. The main pay shoot extends on both sides of the shaft and is somewhat irregular in shape, though it is stated that the richest ores are from shoots dipping south on the plane of the vein. The greatest length of stoped ground is 2,000 feet. On the thirteenth level the vein is split into three parts, the division extending several hundred feet north and south. This break, occurring in the main shoot, made the exploitation very difficult and diminished the tenor of gold in the veins. Excellent ore 18 inches wide was, however, stoped on the twentieth level north in 1894. The distance between the branches makes it doubtful whether they will join again in depth. Several strong cross seams run through the northern part of the mine, and have been observed to fault the vein a little. The relations illustrated in fig. 37 were shown in the stopes a little below the twentieth level.

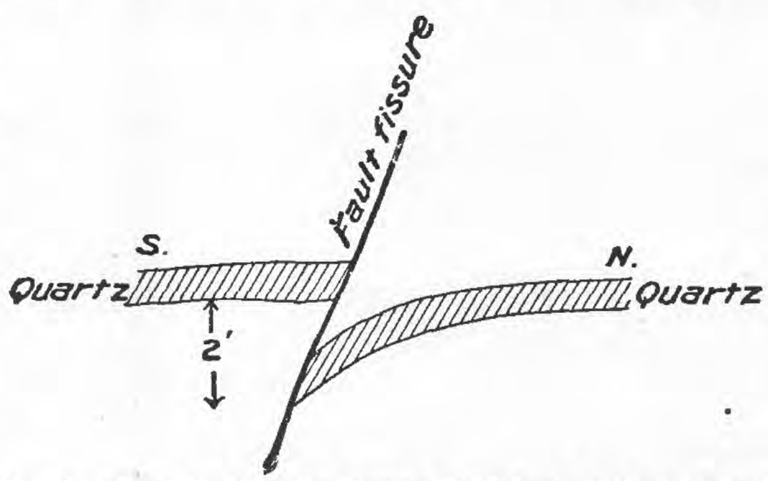

FIG. 37.—Longitudinal section, showing fault, Ophir Hill vein, twentieth level, Empire mine.

The Rich Hill vein, dipping 30° W., and approaching the Ophir Hill in depth, has been opened to a less extent by an incline shaft and by means of a crosscut from the sixth level on the Ophir Hill shaft. Good ore was stoped from this vein in 1894 on the so-called Rush and Laton shoot, which is said to be 200 feet long. For some distance above the sixth level the vein is divided in two, joining again above the fifth level. The hanging vein is the better, showing about 12 inches of massive quartz with pyrite and galena, and is inclosed in diabase, hard and fresh close up to the vein. This complete absence of crushed or altered wall rock is somewhat unusual. Brown opal containing coarse gold has been noted from this shoot.

The Rich Hill continues southward through New Ophir and Daisy Hill claims, on which the developments are not extensive. A shaft, 300 feet on the incline, was sunk on the latter many years ago, and the mine is reported to have been reopened in 1895. A branch vein is said to connect with the Ophir Hill vein at the Prescott shaft.

THE ORLEANS MINE.

The Ophir Hill vein doubtless continues southward toward the Orleans mine, though the croppings do not show quite continuously on the surface. The old Orleans shaft was sunk to a perpendicular depth of 100 feet; the new shaft, started a few years ago, inclines 35° W., the croppings lying some distance east of the shaft. The depth is 325 feet, with drifts at 200 and 280 feet. A considerable amount of ore has been produced by the Orleans. The gold is 790 fine. There are 3 per cent of sulphurets, averaging 3.5 ounces of gold and 0.7 ounce of silver. The vein continues southward by Mayflower, Prescott, Betsey, and King Hill shafts, all worked to some extent many years ago. King Hill and Prescott shafts were sunk to a depth of 300 feet on the incline. The long Orleans tunnel drained the surface workings as far south as the Betsey mine. This narrow vein appears to have been characterized by a strong percentage of arsenopyrite and rich ore.

HEUSTON VEIN.

Lying parallel with the Ophir Hill vein and several hundred feet east of it is the Heuston, which can be traced only 1,500 feet on the surface. The deep explorations on this vein began in 1861 and were continued until about 1870, since when the mine has been idle. The shaft is 300 feet on the incline, dipping 25° W., and the several levels extend north and south. The vein is very narrow, averaging 8 inches, inclosed in hard diabase, but very rich. It yielded $500,000 between June, 1864, and April, 1867. Some ore containing $160 per ton was mined in 1867. The expenses were estimated to have been $45 per ton in 1867.[1]

THE SEBASTOPOL VEIN.

At a distance of 600 to 700 feet east of the south end of the Ophir Hill lies the Sebastopol, also dipping west at 35°. The Sebastopol shaft was worked 180 feet on the incline between 1856 and 1858, yielding $200,000, and was again opened for a short time in 1880.

The southern end of the vein has recently been opened by the Electric shaft, sunk to a depth of 400 feet, dipping 30° W., and with drifts extending 150 feet north and south. South of the shaft the vein turns to the southwest. The country rock is a diabase-breccia; the vein is 1 to 2 feet wide, and the ore carries finely divided gold with pyrite and some arsenopyrite and galena. On this and adjoining veins the pay shoots trend rapidly to the south on the plane of the vein. Two smaller veins, which have been worked to some extent and proved to pay well, lie between the King Hill and the Electric, the Sanders on the east and the Payday on the west.

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[1] Notes from Bean's Directory.

THE OSBORNE HILL VEIN.

General features.—Beginning a short distance west of King Hill shaft, the Osborne Hill vein can be traced half a mile south-southeast to beyond the Centennial shaft. On the east side of Osborne Hill there are no outcroppings for 3,000 feet, when again a vein appears which possibly may represent the extension of the Osborne Hill, having the same direction of strike and dip and the same characteristics of ore. Very little work has been done on this southerly extension.

The Osborne Hill mine.—The principal developments are found at the Osborne Hill mine. From 1852 to 1857 the vein yielded large returns from the surface ore, the stopes extending 100 to 180 feet on the incline for 200 feet south of the shaft and 800 feet north. Between 1865 and 1870 the main shaft was sunk to 400 feet and much ore was extracted. The mine was idle from 1870 to 1894, when it was opened again, the shaft sunk to 600 feet on the incline, the drifts extended, and a 20-stamp mill erected.

The character of the wall rock varies somewhat; it is in part a very fine grained uralite-diabase, in part a hornblende-porphyrite or a breccia of porphyrite and brownish argillite or fine-grained sandstone.

The vein strikes north-northwest with many local curves and irregularities, and the dip varies from 29° in the upper levels to 44° in depth. In some parts, as on the fifth level north, the vein runs down to a seam, which, though containing rich ore, is too small to work. The main ore body was exposed on the fifth level north, which shows excellent ore 3 to 4 feet wide and said to average $30 to $40. The foot wall is well defined, the hanging less so. The vein makes less the impression of a continuous open space filled with quartz than of a zone of crushed rock 1 to 3 feet wide, containing many smaller open fissures and spaces subsequently filled with quartz. Comb structure and vugs filled with crystals are very abundant. Banded structure by deposition and ribbon structure by subsequent sheeting both occur. The country rock between and adjoining the walls is very much decomposed and chiefly converted into sericite, there being but little carbonates. It is, besides, filled with arsenopyrite in small crystals. In the quartz free gold is rarely visible. The ore contains arsenopyrite, with some pyrite and a little zincblende, galena, and occasionally chalcopyrite, in all 1¾ per cent sulphurets. The brown blende occasionally contains coarser gold. The gold is 767 fine; the sulphurets contain very little silver.

In a few places there are indications of a system of joints dipping 30° E. Several crossings cut the vein without faulting it, and have an easterly strike and a steep dip north or south. Occasionally the cross seams carry some quartz, and in one instance tetrahedrite was found on one of them.

A branch vein with steep dip, called the Shoofly, lies to the west of the Osborne Hill mine.

The Centennial mine.—South of the Osborne Hill mine probably the same vein is worked by the Centennial shafts. This mine was worked between 1876 and 1883, producing a reputed total of $600,000. In 1893 work was resumed on the new shaft, but soon stopped again. There are two shafts; the old one is several hundred feet deep, and the extensive dumps indicate that a great amount of work has been done from it. The new shaft, 300 feet farther south, is 650 feet deep on the incline. The vein dips W. 30°, and is contained chiefly in porphyrite-breccia with many brownish fragments of sedimentary flinty rocks. The quartz, which averages 1 foot in width, contains finely divided gold and a considerable amount of sulphurets, chiefly arsenopyrite, with much pyrite and a little galena. Calcite, in large cleavage pieces, is frequently found in the altered country rock adjoining the vein. The pay shoot is said to be 250 feet long, rapidly trending south on the plane of the vein. One or two cross seams cut the vein without faulting.

THE LAFAYETTE AND COMET VEIN.

Extending diagonally across Osborne Hill, with a strike a little west of north, this strong vein can be traced for a distance of 1¼ miles. Comparatively little work has been done on it. At its northern end the Conlan shaft was sunk 190 feet on the incline in 1892, disclosing a vein of 26 inches and some good ore. The vein dips 42° W. and is inclosed in porphyrite-breccia. Between the Conlan and the Lafayette tunnels the outcrops are not very distinct, but south of the latter mine they can be traced easily. In the Conlan there are said to be two ore shoots pitching southwest.

The Lafayette tunnel strikes the vein 450 feet from the mouth, and drifts are extended on the vein 80 feet north and 500 feet south. The vein dips 25° W.; the ore is ribboned quartz with pyrite and galena, and contains $20 to $50 per ton.[1]

The Comet tunnel, farther south, cuts the ledge 600 feet from the mouth, and a considerable amount of ore has been stoped at various times.

At the southern end there are two strong veins on the Indiana claim; on the more westerly of these a perpendicular shaft has been sunk 80 feet deep.

THE VEINS OF ROUGH AND READY AND DEADMANS FLAT.

In the vicinity of Rough and Ready, 4½ miles west of Grass Valley, there are several smaller veins, usually rich in pyrite and other sulphides.

The Osceola vein, inclosed in amphibolite, striking east-west and dipping 60° N., has been developed by two tunnels and a small shaft. The *Ironclad*, in gabbro, 5 miles west of Grass Valley, dips 45° W., and is opened by a 200-foot inclined shaft. The ore is strongly sulphureted,

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[1] Eleventh Ann. Rept. State Mineralogist.

containing about $20 per ton. The vein is said to be 2 feet wide and was worked to some extent in 1881.[1]

Deadmans Flat is situated 3½ miles to the west-southwest of Grass Valley, on the rolling plateau extending in that direction. The surface gravels in the gulches of this vicinity were extremely rich in coarse gold, and several promising quartz mines have been found there. The veins, which are indicated on the Smartsville sheet,[2] lie in the mostly massive, rarely schistose, amphibolite area between two masses of gabbro. The grain of the rock, which is chiefly of dark color, varies greatly, and in places unaltered diorite or gabbro is found. The whole area appears to be a partially dynamo-metamorphosed complex of diorite and gabbro. The veins form three groups, with a generally northerly strike, and generally dip west. On the north lie the South Star claims, followed southward by the California mine, also known as the Pittsburg. This vein, which dips WNW. 65°, has been worked at intervals, and at times has been a considerable producer. The shaft is 280 feet deep. The ore contains coarse gold, 5 to 10 per cent of sulphurets, and a total of from $40 to $75 per ton. The vein is said to average 1 foot in width. It is credited with 250 tons of ore in 1875, producing $20,000, and with $16,000 in 1891. The total production is not known.

The Seven-thirty vein, one-half mile south of the California and dipping 55° W., extends through two locations. It has been worked at various times by two incline shafts 200 feet deep. The vein is 18 to 24 inches wide, and has produced a notable amount of ore. The surface ore has been worked for several hundred feet. The ore is white quartz with but little sulphurets, and is said to average $20 per ton in the shoots. The superintendent states that the fineness of the bullion exceeds 900, which certainly is most unusual. The mine is credited with $11,200 in 1869. In 1893, 300 tons were crushed, yielding $6,000.

The Normandie veins are located 1 mile east of the Seven-thirty, strike a little west of south, and dip 40° W. The shaft is 120 feet deep. The two veins, 40 feet apart, average 6 inches in width, but contain very high grade ore. A cross vein, called the West Normandie, dips 35° N.

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[1] Mint reports.

[2] Geologic Atlas of the United States, folio No. 18, Smartsville, Cal.

CHAPTER XVII.

SUMMARY.

INTRODUCTION.

The mining districts of Nevada City and Grass Valley are situated in Nevada County, 135 miles northeast from San Francisco, on the western slope of the Sierra Nevada, at an elevation of about 2,500 feet.

A great number of important gold deposits, consisting of quartz veins and gold-bearing gravels, are concentrated in this vicinity.

The districts were discovered in 1849 and the mines have been worked continuously since that time. At present the quartz-mining interests are by far the more important. The districts are estimated to have produced a total of about $113,000,000. During the last years the Grass Valley district has annually produced an average of $850,000 and the Nevada City district $400,000, all in gold; the silver production is comparatively insignificant.

GEOLOGY.

Distinction is made between the Tertiary and Recent rocks, called the *superjacent* series, and the pre-Tertiary rocks, called the *bed-rock* series. The latter contains the quartz veins, the former the placer deposits resulting from the disintegration of the veins. The districts lie at the border line between the foothills of igneous rocks and the middle slopes of sedimentary formations of Jurassic or older age. The rocks prevailing in the vicinity are chiefly of igneous character. Only a few areas are of sedimentary origin, and consist of siliceous argillite, slates, sandstones, and schists of partly Jurassic, partly Carboniferous age. They are generally altered, but rarely so much that their origin can not be recognized. The igneous rocks consist of granodiorite, diorite, gabbro, pyroxenite, peridotite, diabase, and porphyrite. By metamorphic processes amphibolites have in places been formed from the diorite, gabbro, diabase, and porphyrite, while the pyroxenite and peridotite often have been changed to serpentine. The igneous rocks are of Juratrias or later age, with the possible exception of the diorites, gabbros, and peridotites. Beginning with the latter, the eruptions were continued by the diabases and porphyrites and closed by the great intrusions of granodiorite of probably early Cretaceous age. The period of maximum intensity of volcanic activity appears to be contemporaneous with or a little later than the close of the Jurassic.

The oldest sedimentary rocks were folded and compressed before the igneous activity had commenced. After the close of the Jurassic a second folding and compression took place, which metamorphosed many of the igneous rocks just erupted. Subsequently to the intrusion of the granodiorite the metamorphosing influences have been slight, but the range was subjected to great compressive stress, producing systems of joints and fissures on which the quartz veins were formed.

In discussing the metamorphic processes, distinction is made between dynamo-metamorphism, dynamo-chemical metamorphism, common hydro-metamorphism, hydro-thermal metamorphism, contact metamorphism, and weathering, all of which are shown in this vicinity. The different ways in which pyrite and pyrrhotite may form are described; also the course of the alteration in the feldspars, which chiefly are converted to micaceous products, and possibly scapolite, but not extensively to kaolin.

THE FISSURE SYSTEMS.

The compressive stresses to which the range was subjected after the intrusions of granodiorite produced joint systems in different directions, traversing all rocks of the bed-rock series. Sometimes the joint plates are thin and a sheeting of the rock is produced; at other places the spacing was much larger and a series of parallel fissures was produced. The fissure systems may be divided into north-south veins dipping either east or west at moderate angles, averaging 35° or 40°, and the several groups of east-west veins dipping either north or south at high or low angles. Each direction of strike has its two directions of symmetrically opposite dip, which are referred to as *conjugated* systems. The faults on the veins are in general small, but on the Merrifield and Ural veins great movement has taken place, resulting in a throw of probably over 1,000 feet measured along the dip of the vein. Nearly all faults recognized are overthrusts. The north-south veins are older than most of the east-west veins and are faulted by them. It is further shown that the fissures cross the contacts without being influenced by them, except as the susceptibility to deformation and breaking of different rocks is concerned.

The origin of the fissure systems is shown to be compressive stresses, which will, as indicated by experiments, produce such conjugated fractures as are observed here.

PRODUCTS OF VEIN FORMATION.

The products of the vein-forming agencies are:

1. Quartz with native gold and metallic sulphides. This is formed by deposition in open spaces along the fissure and constitutes the richest and generally the only kind of ore; and

2. Country rock, altered by metasomatic processes. This as a rule contains very little, if any, gold.

The gold is generally in a finely divided state, though in many mines coarse gold also occurs. The free gold occurs in similar quantities at all depths and is generally associated with sulphides. The value of the free gold generally far exceeds that of the gold and silver in the sulphides, though in a few mines the latter may equal the former. The fineness of the gold bullion varies from 700 to 850, and averages about 800. The sulphurets, consisting of predominant pyrite with galena, blende, chalcopyrite, sometimes arsenopyrite, and small quantities of tellurides, generally make from 2 to 3 per cent of the ore, ranging from one-half to 7 per cent. The value of the sulphurets varies from $40 to $400 per ton, the quantity of silver by weight frequently exceeding that of the gold. Small quantities of bismuth and cadmium have been found. The value of the ores ranges from $6 upward. The average value is probably between $15 and $20 per ton. The Grass Valley and Banner Hill veins carry somewhat richer ore than the Nevada City mines. In structure the ore may be: (1) Massive, carrying massive quartz with irregularly distributed sulphurets. (2) Banded by deposition. Both these forms show transitions to comb structure and drusy structure. (3) Ribbon structure by subsequent movement on the vein. This is explained and illustrated in detail. The quartz under the microscope shows all phenomena of crushing, and the sulphurets are pressed out. The gold is often concentrated on the planes of sheeting by a concentration subsequent to the movement. (4) Banded structure by reopening or successive openings and fillings of a fissure.

The quartz is shown to contain soluble sulphates and chlorides.

The rocks next to the walls and fragments included in the quartz show extensive alteration to carbonates, sericite, and pyrite by metasomatic processes; the pyrite contains very little gold, and very rarely is there any free gold in the wall rock. The chemistry of the process is explained: Silica and soda are removed; potassa, lime, and sulphur are introduced. All ordinary minerals in the rocks are attacked by vein solution. A silicification of the wall rocks is not recognized.

Along certain veins there is also an extrusive mechanical alteration of the country rock, consisting in the production of schistose structure and crushing of the individual minerals.

STRUCTURE.

The simplest type of structure is produced by filling of open spaces along a single fissure, the open spaces being caused by movement along the plane of the somewhat irregular break. More complicated structure may result where there are two or more fissures, nearly parallel, the space between which is largely filled with country rock, usually brecciated or crushed. Then the quartz will deposit in the open spaces between the rock fragments, forming more or less irregular and winding veins between the parallel fissures.

The width of the quartz along the fissure varies greatly, and places where the vein pinches out to a mere seam occur abundantly in most veins. The average width of the larger veins may be from 2 to 3 feet, while by far the largest number are very much narrower. Some of the most productive veins average but little over a foot in width.

No distinct relation between country rock and the contents of the veins can be recognized. Veins occur in practically all rocks of the district. The metasomatic processes are almost identical in all rocks. The character of the filling—the quartz—varies greatly, but is not constant for the same rock. It even varies in different parts of the same vein in the same rock. Some veins in granodiorite and argillite are rich in silver and carry abundant sulphides.

The influence of locality is very prominent; generally veins from the same vicinity carry similar ores. On the whole, the great concentration of deposits in and about the granodiorites of Nevada City and Grass Valley indicates that the veins are genetically connected with this large intrusion of acid magma.

PAY SHOOTS.

The rich ore usually occurs in fairly well-defined bodies, or pay shoots. They are, as a rule, long-drawn bodies with their maximum extension in the general direction of the dip, but with an ordinarily well defined pitch on the plane of the vein. The rule in this vicinity is that the ore shoot dips to the left of an observer standing on the apex and looking down in the direction of the dip.

The pay shoots vary in length from a few feet—those generally being called pockets—up to several thousand feet. On each larger vein there are usually several pay shoots. It is very common for one shoot to cease in depth or be subject to local impoverishment, but thorough exploration will usually result in finding new shoots or a continuation of the old one. There is no gradual impoverishment of the ore in depth, while frequent changes in value occur. The depth at which gold quartz is no longer deposited has not been reached in our present explorations.

GENESIS.

The veins were formed by aqueous deposition and by thermal waters containing carbonates, silica, alkaline sulphides and sulphates, besides gold and metallic sulphides, the latter probably in a state of solution. The heavy metals were probably leached from the rocks traversed by the solutions at a great depth. It is shown that the heavy metals in the veins have probably not been derived from the immediately adjoining wall rock, though gold and heavy metals may, and in fact do, occur in them.

The solubility of minerals at different temperatures and pressures is investigated, with the result that there is generally not an indefinite increase in solubility by rising temperature and pressure, but a certain maximum which can not be exceeded. From this it appears probable that a decrease of temperature and pressure in waters approaching the surface is not an entirely dominant factor in the formation of mineral deposits. Considerable silica and sodium salts have been constantly subtracted from the wall rock during the vein-forming process, and a part of the quartz in the vein is derived from this silica. It is suggested that the deposition might be due to a disturbance of the equilibrium in the concentrated solution by material constantly added from the wall rock. The gold and the sulphides were probably largely deposited mechanically with the silica. The country rock appears to have had no special precipitating influence on the solutions.

THE SUPERJACENT FORMATION.

The auriferous gravels of Neocene age are briefly described, and it is shown that they had not accumulated to any considerable depth at the beginning of the volcanic period.

The bed-rock surface upon which they rested is restored and shown by contour lines. This Neocene topography is discussed in detail, and it is shown how the incongruous features of the map in regard to the grade of the streams are made harmonious by the supposition of a tilting of the Sierra Nevada along its eastern edge. The rocks of the volcanic period, including rhyolite and andesitic tuffs, are briefly described, and it is shown that much of the heavy gravel bodies of Nevada City was due to the damming of the channel by the first rhyolitic flows. The last andesitic mud flows covered the whole country here described, Banner Hill and Osborne Hill alone projecting above the level of the lava field.

ADDENDUM.

According to data kindly furnished by Mr. Charles G. Yale, statistician United States Mint, San Francisco, the production of the Nevada City and Grass Valley mining districts in recent years, including all quartz and placer mines, is as follows:

	1893.	1894.	1895.
Nevada City, including Willow Valley.	$578,523.72	$506,380.22	$642,799.76
Grass Valley, including Rough and Ready and Deadmans Flat	845,289.00	697,432.25	564,908.64
Total	1,423,812.72	1,203,812.47	1,207,708.40

GEOLOGY OF SILVER CLIFF AND THE ROSITA HILLS, COLORADO.

BY

WHITMAN CROSS.

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GEOLOGY OF SILVER CLIFF AND THE ROSITA HILLS, COLORADO.

By Whitman Cross.

PREFATORY REMARKS.

The geological investigation of the area discussed in this report was undertaken in the summer of 1883 by the Rocky Mountain Division of the Survey, under the supervision of S. F. Emmons, geologist in charge. The geological map was practically completed in that year, though additional information has been obtained on several later visits to the region. It was at first planned to publish the results in monograph form, but the rapid decline of the district as a mining camp and the resulting inability to obtain satisfactory information concerning some of the most interesting ore deposits have caused much delay in completing the report and make the present form of publication seem more appropriate. Although the field work was done while the writer was assistant to Mr. Emmons, it has been thought best to separate the following report on the geology, for which the writer is alone responsible, from the succeeding discussion of the ore deposits by Mr. Emmons, to whom, for his generous courtesy in advocating this treatment, as well as for the benefit of his constant advice and kind interest, the writer wishes to express sincere thanks.

During the progress of the work assistance was received from many persons, and acknowledgments are specially due to Messrs. C. H. Johnson, C. G. Mathews, G. F. Barker, C. H. Brewer, Mr. Howard, and others of Silver Cliff or Rosita. Mr. L. G. Eakins, at the time a chemist in the Denver laboratory of the Survey, served as field assistant in 1883, and rendered valuable services.

CHAPTER I.

INTRODUCTION.

POSITION OF THE DISTRICT.

The district whose geology is to be described in this report lies on the eastern slope of the Wet Mountain Valley, south of the Royal Gorge of the Arkansas and about 25 miles southwest of the city of Canyon. The valley, named from the Wet Mountain Range, which bounds it on the east, is one of the numerous depressions between mountain ranges so characteristic of the Rocky Mountain system in Colorado. It is wider than most of the intermontane valleys, but differs from the "parks" in that it is not surrounded by mountain masses, being open at the north and south.

The valley lies between nearly parallel mountain ranges having a general direction north-northwest. The western range has retained its picturesque Spanish name, "Sangre de Cristo," while that on the east, once known as the Sierra Mojada, has now received the synonymous title of the Wet Mountains. The valley itself is about 25 miles long, and varies in width from 12 miles at its southern end to nearly 20 miles toward the northern limit. Its average elevation above sea level is about 8,500 feet, 3,000 feet higher than the plains at the eastern base of the Wet Mountains.[1]

Toward the southern end of the valley it is crossed by an almost imperceptible watershed, but not far to the south of this divide the slope descends rapidly to Huerfano Park, which is an embayment of the plains to the west of the southern end of the Wet Mountains. From the Huerfano divide, which has an elevation of 9,000 feet and is a plain sloping up gently on either side toward the foothills of the bounding ranges, the Wet Mountain Valley stretches northward for 25 miles, its lowest portion, a broad area of green meadow lands, lying somewhat to the west of the median line between the two ranges and descending about 1,000 feet in this distance.

At the northern end the valley is separated by a series of low hills into two slightly diverging portions, through the eastern of which the drainage of the valley proper continues on by way of Grape Creek, while in the western, beyond a watershed whose rise is not perceptible to the eye, the streams flowing out from the ravines of the Sangre de Cristo Range are gathered into Texas Creek and reach the Arkansas River through a winding valley of moderate descent and general

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[1] The reader is referred to the well-known Hayden Geological Atlas of Colorado, Sheets XIII and XVI, for a general presentation of the geology of this portion of Colorado.

northerly course. *After leaving the valley, Grape Creek cuts a narrow* and deep gorge to the Arkansas, which it reaches at the lower end of the Royal Gorge. The branch of the Denver and Rio Grande Railroad which formerly approached Silver Cliff through the canyon of Grape Creek experienced many damaging floods, and in 1888 it was so completely washed away for long stretches that it was abandoned.

The Wet Mountain Valley possesses a beauty of its own, differing from that of any other of the many beautiful mountain valleys of Colorado. The long, gentle slopes of Pleistocene material sweep gracefully from its bottom lands up to the foothills of the neighboring mountains so gradually that, though attaining an average elevation of a thousand feet above the valley, their rise is in many places scarcely perceptible to one standing upon them.

There is a marked contrast in the character of the eastern and western slopes of the valley, which is dependent on the differing physical and geological structure of the mountain ranges upon whose flanks they rest. The Wet Mountains, on the east, form a comparatively low range of extremely irregular structure. Their summits rarely rise above 11,000 feet, and constitute a series of rounded, irregular, and often isolated hills, separated by comparatively open and shallow valleys, whose inclination is sometimes so slight that it is difficult to determine in which direction their natural drainage lies. The main rock of which these hills are composed is a coarse-grained and very readily disintegrated granite, and the valleys are filled to a very considerable depth by this gravel of disintegration, which is extremely porous and permeable to water. In the upper part of the range the water that falls rarely runs upon the surface, but, sinking through the porous material, follows the surface of the underlying rock, to appear here and there in springs, or else to issue in the bed of some of the larger streams at a considerably lower level. Hence the eastern slopes of Wet Mountain Valley have relatively few running streams, and present a rather dry and barren aspect. The hills themselves, however, are covered with an open growth of sturdy yellow pines, and the soil supports a natural and, for this country, abundant growth of bunch grass, whose prevailing straw-yellow tinge forms an agreeable background for the more somber green of the pine foliage and the red tones of the massive granite exposures.

The Sangre de Cristo Mountains, on the other hand, rise to over 14,000 feet elevation, or 6,000 feet above the valley, and form a relatively narrow ridge or sierra, scored by deep ravines or canyons walled in by steep cliffs several thousand feet in height. Seen from the valley, especially toward sunset, they present a most imposing appearance. Their skyline, formed by a series of pyramidal peaks, between which are some of jagged or castellated form, with sharp columns projecting upward, separated by narrow crenelated openings, is one of the most striking to be found in any mountain range.

There is an abundant rainfall on the Sangre de Cristo Range, and the water rushes in torrents through the deep gorges cut in the Carboniferous conglomerates to the Wet Mountain Valley, carrying abundant detritus and building up broad, flat alluvial cones, which are a marked feature of this side of the valley.

The district to be described extends from the bottom of the valley about 10 miles diagonally up the slope toward the Wet Mountains. Silver Cliff and Rosita, the two principal mining towns, are situated at opposite extremes of the area. Down near the valley bottom is Silver Cliff, while Rosita nestles among a little group of hills to the southeast. The details of topography are well shown on the topographic map, Pl. XXV (in pocket), and the views of Pls. XXVII and XXXI show clearly the relations of the two mining districts to the valley slope.

Pl. XXVII, while intended to show the character of the country in the vicinity of Silver Cliff, may also serve to illustrate the description which has been given of the valley and the Sangre de Cristo Range. The view is taken from the White Hills, north of Silver Cliff, looking over the town, which is half hidden, and up to the head of the Wet Mountain Valley. The view in Pl. XXXI shows the gradually ascending slope of the valley from Silver Cliff for 3 miles to the base of the Rosita Hills, and the general contour of these hills.

PRELIMINARY SKETCH OF THE GEOLOGY.

The Wet Mountain Valley owes its gentle slopes to the alluvial gravels which have been washed down from the mountains on either side. On the west the bounding Sangre de Cristo Range is composed mainly of coarse Carboniferous sandstones and conglomerates. At the base of the mountains there is apparently a profound fault of unknown age, which has not been examined in detail. On the eastern side of the valley the slope is more irregular, being interrupted by hills and ridges consisting on the one hand of gneiss or granite and on the other of volcanic materials. The mines of the Silver Cliff and Rosita districts are for the most part in volcanic rocks, but the area mapped includes also a number of hills of granite and gneiss.

The eastern portion of the area to be described is occupied mainly by the volcanic group of the Rosita Hills. There are here both massive and fragmental volcanic rocks, and the investigation has shown that at this point there was once a volcano whose products accumulated upon a surface very similar in character to that of to-day. These hills exhibit a succession of volcanic rocks—andesite, rhyolite, and trachyte—in both fragmental and massive forms, and although the complex has been much modified by agents of decomposition and erosion, a fairly complete record of the history of the Rosita volcano has been made out.

At and near Silver Cliff there are massive and fragmental rocks belonging to the rhyolitic period of the Rosita volcano. No other rocks of the eruptive sequence are found at Silver Cliff, and the modification of the valley slope is there much less pronounced than in the Rosita Hills.

The nonvolcanic hills of the area to be described represent the ancient gneisses and granites which form the adjacent portions, at least, of the Wet Mountains and their western slope. The present investigation has necessarily been too limited to show the relationships of these old gneisses and the later granites to those known to play so important a rôle in other mountain ranges of Colorado, but from later studies elsewhere it appears that the red granite dikes and stocks of the Wet Mountains are probably not of Archean age, but belong to the Algonkian or early Cambrian. The gneisses cut by these granites may be Archean, but there is no direct evidence on this point.

No sedimentary formations appear in the region studied except a very local and probably recent lake bed, and the stratified rhyolitic tuffs of the Silver Cliff basin, in greater part revealed only by the Geyser shaft.

The Pleistocene mantle, which barely conceals the gneisses and volcanic rocks over considerable areas, is probably quite deep in the lower parts of the valley, and doubtless many unevennesses of the slope are obliterated by the gravels washed down from the eastern hills.

GEOLOGICAL RELATIONSHIPS OF THE DISTRICT.

The volcanic phenomena of the district may be compared with those nearly or quite contemporaneous in other portions of Colorado. The fossil leaves found in the rhyolitic mud flows of the Rosita Hills, while few in number, serve to fix the early Eocene as the most plausible date for the volcanic activity, and this is also the general age for extensive series of volcanic outbreaks in other parts of the State.

The Hayden Survey map of Colorado shows volcanic rocks as occurring on the western slopes of the Wet Mountains in much more connected form than is actually the case, but the whole of this slope was not explored in connection with the examination of the Rosita district, and it is possible that other small centers of eruption may exist farther south on the flank of the range. It does not seem probable that a volcanic center at all corresponding in character to that of the Rosita Hills can have escaped the attention of prospectors, but eruptions contemporaneous with certain ones of the Rosita vent may well have occurred in the vicinity.

The volcanic center at Cripple Creek, in El Paso County, some 40 miles northward from the Rosita Hills, is in some ways especially comparable with the latter. The comparison is most striking as regards the long succession of eruptions at small vents rather than in the character of the products. But each volcano seems to have passed through a very complete cycle of eruptions, including, near the close, solfataric action and a period of hot-spring waters, followed apparently by ore deposition. These later phases of activity at the eruptive centers did not result in very similar products.

Both the Cripple Creek and Rosita volcanoes are to be regarded as small, outlying vents connected in origin with the much larger eruptions of the San Juan and of the South Park regions, which were in part also of Eocene age, though probably continuing into the Miocene.

CHAPTER II.

DESCRIPTION OF ROCK FORMATIONS.

INTRODUCTORY REMARKS.

The rock formations of the Silver Cliff-Rosita region will be described in groups which are for the most part indicated in the preliminary geological sketch of the introductory chapter. In the first place, there is the ancient complex of gneisses and granites through which the volcanic products of the largest group have burst. The granites are later than the gneisses, but both belong to periods probably far antedating those of other rocks of the region, and in spite of certain structural differences there is much in common in the conditions under which these rocks were formed, and they may naturally be grouped together.

The eruptive rocks of the Silver Cliff-Rosita Hills district, which are later than the granites, present a variety quite unusual in such a small area. They may be considered in two divisions corresponding in a general way to differences in time and conditions of eruption. The older of these divisions embraces three rocks—peridotite, diabase, and syenite—which are known in dikes only, and belong to a period much earlier than that in which the others were erupted. The later series includes rocks closely related to one another in time and conditions of origin. The older dike rocks do not possess great importance from their mass, but two of them are so widespread and persistent in their characteristics that they become of considerable interest. The relationships of these rocks to one another in point of time have not been ascertained, nor do we know how far the period of their eruption antedates that of the second group, but it is clear that they penetrated the gneiss in dikes after it had been folded and brought approximately to its present position, and also that they were eroded in common with the gneiss in producing the surface upon which the later rocks were poured out.

In the second period of eruption there appeared a remarkable sequence of rocks under truly volcanic conditions. At least seven types of considerable geological importance can be distinguished, and for the most part the relationships of the various forms are clear. A number of minor types belong in this series. These rocks are found cutting one another and also spreading out upon a surface corresponding closely to that of the present day. The Rosita Hills are built up by them and more than half the area of the map is occupied by their masses. The problems connected with their origin, their relations, and the secondary changes to which they have been subjected are all of prime importance.

After the igneous rock types have been characterized as they appear in their fresh state, it is necessary to describe the products of extreme decomposition to which some of them have been subjected, since in many places in the Rosita Hills considerable masses have been so much altered that they retain but scanty traces of the structure of the original rock. Some of these secondary products are more prominent in the topography of the hills than any of the primary types.

The lake-bed deposits and the surface materials of the district, while distinct geological features, do not possess characteristics demanding much detail in description.

GNEISS AND GRANITE.

OCCURRENCE.

At the time when the field work for this report was done the granites and gneisses of the Silver Cliff region were supposed to belong to the fundamental complex of the Archean, to which, indeed, nearly all the so-called crystalline schists of the Rocky Mountains have been generally referred. With the recognition by Emmons[1] and Van Hise[2] of the fact that pre-Cambrian sediments occur in the mountains of Colorado in intimate and as yet undeciphered relations to granites and gneisses, it became clear that the age of the latter must in some places be open to doubt; and the discovery by the writer that the granites of the Front Range in the Pikes Peak district[3] are later than certain quartzites thought to be of Algonkian age, of which they contain many large fragments, makes it almost certain that the granites of the Silver Cliff region do not belong to the Archean, and raises some doubt concerning the gneisses.

The gneisses and intruded granites which form all the northern portion of this area, and appear elsewhere in isolated exposures where the eruptive or the Pleistocene covering has been removed, are but a part of a great system well shown in the adjoining country on the north and east. These outlying districts could not be carefully examined. As the leading gneissic type of the Silver Cliff section has not been identified elsewhere in corresponding development, and as the structure of the old schistose formations of the Rocky Mountains has not yet been deciphered, it is impossible to point out the relative position of these rocks to those of other parts, even of the Front or Colorado Range.

The system of gneisses examined has a general strike northeast to southwest, with a northwesterly dip, which is seldom less than 45°, and is prevailingly between 60° and 90°. The map thus represents a

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[1] Orographic movements in the Rocky Mountains: Bull. Geol. Soc. America, vol. 1, 1890, p. 257.

[2] Bull. U. S. Geol. Survey No. 86, 1892, pp. 308-326.

[3] See descriptive text of the Pikes Peak Folio, Geologic Atlas of the United States, 1894.

section several thousand feet thick across the strike of the gneisses. There is but little local crumpling, and no indications of a duplication by faulting or folding were observed. Neither the summit nor the base of the series to which the rocks belong is shown in the region, and the prevailing dip is the only evidence as to the original order of superposition.

The prevalent granite type of the region, an even- and fine-grained reddish biotite granite, traverses the gneisses in dikes and small stocks, or may be intruded with approximate regularity parallel to the gneisses. Coarse pegmatitic dikes also occur locally, often cutting the fine-grained granite and extending a short distance out into the surrounding rocks.

DESCRIPTION OF TYPES.

VARIABLE GNEISSES.

The gneisses of variable constitution make up more than half the total thickness of the banded section. They consist in a large degree of the potash feldspars microcline or orthoclase, with quartz and a local development of biotite, muscovite, hornblende, or augite, which gives rise to various modifications. By the appearance of a soda-lime feldspar with augite and hornblende, and by the suppression of quartz and microcline, there arise transitions to some of the other types to be described.

Gneisses of persistent characteristics maintained through considerable thicknesses are not often prominent. A gray, rather fine-grained biotite gneiss is perhaps more common than any other well-defined type, but in general the gneisses are reddish, owing to the pink microcline, and the constituent minerals are not uniformly distributed, certain ones being concentrated in particular layers or in thin streaks, so that uniformity in composition through a thickness of many feet is rarely found.

Of the variations in mineral constitution which have been noticed, a few of the more important ones may be mentioned. Quartz, biotite, hornblende, and muscovite are frequently segregated in thin layers or streaks in the predominantly feldspathic mass, and the general character of the complex is determined by the persistence or changeability of such concentrations. Fibrolite appears in certain places, associated with abundant quartz, and sometimes with biotite, and produces fibrolitic gneiss or schist, but such varieties are of very limited extent. Garnetiferous strata have also been observed. By the prominence of a white plagioclase, usually oligoclase, other modifications are produced.

In several places there are massive beds which closely approximate to the dike granite in uniformity of structure and in composition. It seems probable that some of these beds may be intrusive sheets of true granite, but as the gneisses themselves are largely made up of the same minerals as the granite of the dikes, and possess the same characteristics, the question can not be decided except where exposures show irregular contacts.

Distinctly fissile or schistose rocks do not appear prominently anywhere in the observed section. Many of the gneisses possess a parallel structure only through the alternation of materials in different layers as described, and a large number of them show only a subordinate tendency to a parallel arrangement of biotite leaves or of the prisms of hornblende.

AUGITE-HORNBLENDE-GNEISS.

The most clearly individualized rock developed in the banded series is the dark variety prominently exhibited in the Blue Mountains. It is a dark-green, almost granular rock, in which a parallel structure is plain when seen in large masses, though at times scarcely visible in small blocks. It consists of augite, hornblende, and feldspar in uniformly small grains. The hornblende has glistening cleavage surfaces and is of a black or very dark green color. Augite occurs in duller and distinct green grains, thin flakes of which appear brilliant green when, in breaking the rock, they chance to be left as scales over the clear feldspar. The feldspar is chiefly a plagioclase rich in lime, as shown by its optical properties. The amount of feldspar varies greatly in different places. Much of it might be mistaken for quartz on casual examination of specimens, owing to its crystal clearness and its occurrence in rounded grains.

In addition to the minerals mentioned, this typical rock is shown by the microscope to contain small and variable amounts of microcline and orthoclase, which locally increase in quantity to such an extent that distinct varieties result. No accessory minerals of much importance are developed in the purest forms of this rock, and even zircon and apatite seem sometimes entirely lacking. In some places east of Rosita brown garnet and titanite, with more or less titanic iron, are present, but these occur in strata carrying zircon, apatite, and quartz, and certain phases of the rock carry microcline in considerable quantity.

The relation of augite to hornblende in this series of gneisses is a very variable one. In the Blue Mountain gneiss there are many pure grains of each, and also a great many in which the two are intergrown in the most intricate fashion. These formal relations often suggest strongly that the augite is undergoing change to hornblende by paramorphosis. Cores of augite are sometimes surrounded by green hornblende, indistinguishable in character from adjoining pure hornblende grains which may exhibit the prismatic outline, and with this form even penetrate augite. Other grains show the augite substance filled with films and shreds of hornblende in uniform orientation, locally appearing united to solid areas and perhaps connected with an outer zone of massive hornblende. As far as intricacy of intermingling is concerned, some sections afford counterparts of the most typical relationships of these minerals, which have been described by Williams,[1]

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[1] On the paramorphosis of pyroxene to hornblende in rocks, by George H. Williams: Am. Jour. Sci., 3d series, Vol. XXVIII, 1884, p. 259.

Irving and Van Hise,[1] and others, as due to paramorphic change. It is to be noted, however, that Iddings[2] has described the same intimate relationships, produced by original intergrowth, in fresh diorites, and even in partially vitreous andesites, at or near Electric Peak, Yellowstone National Park; and it seems to the writer probable that the intergrowths are primary in this instance.

The lamination of the pure augite-hornblende-plagioclase rock of the Blue Mountains is parallel to the banding exhibited by the thousands of feet of alternating gneisses, and can not plausibly be considered as the effect of pressure upon an old diabase, whose augite has thereby been transformed paramorphically into hornblende, an explanation which will occur to some readers. The same pale-green augite and dark-green hornblende occur all through the sequence of these schists, and the complicated intergrowths are not limited to any special association of minerals. This intergrowth was isolated and analyzed by L. G. Eakins, with the following result:

Analysis of intergrown augite and hornblende.

	Per cent.
SiO_2	48.72
Al_2O_3	9.27
Fe_2O_3	3.77
FeO	6.34
MnO	0.34
CaO	16.79
MgO	14.67
Na_2O	0.19
H_2O	0.18
	100.27

Sp. gr., 3.23 at 18° C.

This composition is not an uncommon one for the augite of many eruptive rocks.

GRANITE.

The fine-grained dike granite consists mainly of pinkish feldspar, which is predominantly microcline and in less degrees orthoclase, with still smaller amounts of white plagioclase and quartz. There is a very subordinate and variable amount of biotite present in most cases. The common accessory minerals, zircon, apatite, and magnetite, are but very sparingly represented in these rocks, and the reddish color is due to the usual cause, viz, flakes and films of hydrous iron oxide included in the

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[1] On the paramorphic origin of the hornblende of the crystalline rocks of the Northwestern States: Am. Jour. Sci., 3d series, Vol. XXVI, 1883, p. 27.

[2] The eruptive rocks of Electric Peak and Sepulcher Mountain, Yellowstone National Park: Twelfth Ann. Rept. U. S. Geol. Survey, Part I, 1891, pp. 606, 610.

microcline or lying between grains of quartz and feldspar. The rock possesses typical regular granular structure and varies in coarseness of grain in different places. The larger masses and the majority of the dikes are, as a rule, moderately fine-grained. The pegmatite dikes are richer in quartz than the rest, and in some cases are practically quartz veins.

DISTRIBUTION OF TYPES.

The section of gneisses and granites here displayed has not been studied with sufficient detail to allow of very accurate statements concerning the distribution of the various rocks which have been described. But a general idea of the lithological character of the series may be given, assuming as a basis that the eastern end of the observed section is the lower.

The rocks of the country east of Rosita, toward Hardscrabble Canyon, are rich in red feldspar, and this gives a prevalent reddish tone to the hills as seen from a distance, for the vegetation is scanty and outcrops are abundant. Looking from Game Ridge, or other hills near Rosita, one can distinguish bosses and irregular masses of red granite in many of the mountains lying south of Hardscrabble Canyon. At the locality of the supposed tin deposits on Antelope Creek, about 3 miles southeast of Rosita, there is a development of plainly stratified rocks bearing augite and hornblende, and locally a dark-brown garnet in considerable quantity. These rocks are allied to the augite-hornblende-gneiss occurring higher in the series, but they do not as a rule contain so much plagioclase. Intrusive granite masses occur abundantly in this neighborhood.

Plagioclastic rocks bearing hornblende and augite appear prominently at the north end of Game Ridge, though in no great thickness. Gneisses of the variability in composition which has been described prevail in all the eastern portion of the area mapped. It is difficult to say whether varieties rich in hornblende and biotite are more or less prominent than the more feldspathic forms, which are usually reddish in color. They seem to alternate in very irregular manner and do not characterize particular parts of the section shown between Game Ridge and the neighborhood of Mount Herring. Granite masses occur scattered throughout, and the same rock predominates among the bowlders contained in the rhyolitic tuff of Wakefield Hill and other places mentioned later on. A fibrolitic gneiss appears in the main eastern tributary of Tyndall Gulch, but has apparently a very slight development, and its significance is not known.

In Mount Herring, and extending southwesterly along the western base of the Rosita Hills, is a band of prevailingly even-grained, gray biotite-granite-gneiss. To the westward from this band and reaching to the eastern ridge of the Blue Mountains more feldspathic gneisses with numerous granite bosses and veins appear.

The three main ridges of the Blue Mountains are made up almost exclusively of the dark and, in places, nearly massive augite-hornblende-gneiss. The bands stand nearly vertical, and the curving form of the eastern ridges is due to the curving strike of the gneisses. No other division of the section is so strongly marked by the preponderance of a single rock type as is the portion here exposed. Yet here, too, one finds beds of reddish gneiss or gray biotite-granite-gneiss intercalated between the purest augite-hornblende-gneisses. On the line of Spring Creek, parallel to the eastern ridge of the mountains, hornblendic gneisses are shown, and similar facies appear on the western slope of the mountains and out to the westward as far as the rocks are exposed.

Granite veins appear very prominently in the dark augite-hornblende-gneiss of the Blue Mountains, the strong contrast between types making them more conspicuous than in other regions where they may be equally numerous.

THE OLDER DIKE ROCKS.

SYENITE.

Syenite is a term very often incorrectly applied by mining engineers and geologists of this country who are not familiar with the current system of rock classification, and it may be well to point out that, by the present universal usage of petrographers, granite and syenite are terms designating parallel series of rocks which differ only by the presence or absence of quartz. Granite possesses quartz as an essential constituent; syenite is free from quartz or contains it in very subordinate amount. Hornblende, which is often erroneously supposed to be the characteristic mineral of syenite, really plays the same part as biotite or augite in producing varieties in both series. Both rocks contain an excess of alkali feldspar (orthoclase or microcline) as compared with lime-soda feldspars. But few true syenites have as yet been described in this country.

DESCRIPTION.

The Silver Cliff syenite is a dull-reddish, almost homogeneous-appearing, fine-grained rock, occurring in numerous long, narrow dikes in the gneisses and granites. It varies somewhat in structure in different dikes, but it can usually be seen by the naked eye to be a finely granular rock composed mainly of red feldspar tablets or grains, with green grains or prisms of amphibole sprinkled evenly through the mass. A few of the feldspars are commonly developed in distinct crystals about 1 cm. or less in length, and a porphyritic structure is thus produced. The small irregular feldspar tablets are arranged with a certain parallelism to the walls of the dike, thus causing a rudely schistose structure. In some dikes the syenite is dense and black adjoining the contact, and grades off within a few inches into normal rock.

On microscopical examination it is found that orthoclase and plagioclase are present in almost equal quantities, and thus the rock stands nearly on the line between syenite and diorite. Both feldspars are equally impregnated by the fine secondary particles of hydrous iron oxide which cause the red color. The amphibole is found to be partly brown and partly greenish-blue, the two varieties being intergrown and apparently formed at the same time. There is a little green biotite, and some secondary epidote, calcite, and chlorite.[1]

A specimen of the freshest rock obtained was chemically analyzed by L. G. Eakins, with the following result:

Analysis of syenite.

	Per cent.
SiO_2	59.78
Al_2O_3	16.86
Fe_2O_3	3.08
FeO	3.72
MnO	.14
CaO	2.96
MgO	.69
K_2O	5.01
Na_2O	5.39
H_2O	1.58
CO_2	.75
	99.96

The specific gravity was found to be 2.689 at 30° C. The analysis agrees well with the mineral composition described.

This syenite is one of the representatives of the type in the "Educational Series" of the Geological Survey.

OCCURRENCE AND DISTRIBUTION.

The most noteworthy dikes of this rock within the limits of the map are in the Blue Mountains. One long one is seen in each of the ridges, and they are prominent by reason of the contrast in color between the syenite and the inclosing augite-hornblende-gneiss. These dikes vary from 5 to 20 feet in width, and pursue straight or gradually curving courses, in one instance observed for more than a mile. They are all nearly vertical and cut the gneisses with general independence of structure planes, and their outcrops are marked by small angular fragments of brick-red color.

Other dikes of syenite are known in the gneiss west of Rattlesnake Hill, 3 miles southeast of Silver Cliff. One more decidedly porphyritic

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[1] A more detailed description of this rock and of several others from this district was published in an article by the writer, "On some eruptive rocks from Custer County, Colorado": Proc. Colorado Sci. Soc., Vol. II, 1887, p. 228.

in structure was found some 12 miles southeast of Silver Cliff, and others are seen in the walls of Grape Creek Canyon at various places. It is said that there are many of these dikes in adjacent areas which were not visited. The analogy with the diabase dikes of the same district is very marked, and leads one to suspect a wide distribution for the syenite.

DIABASE.

DESCRIPTION.

A typical diabase occurs in dikes all through the region between Silver Cliff and the Royal Gorge of the Arkansas, 16 miles to the northward. The rock is dark, dense, and aphanitic in the smaller dikes, while in those 20 feet or more in diameter it becomes plainly granular. This diabase has the normal granular structure (hypidiomorphic) and is simple in composition, consisting of augite, labradorite, and magnetite, with no other important minerals. Chlorite and calcite, as decomposition products, are abundant in most of the rocks.

OCCURRENCE AND DISTRIBUTION.

The diabase dikes of the area studied are seldom large enough to deserve representation upon the map, and it is impossible to trace them for distances corresponding to those of the syenite dikes. This may be in some measure due to their small size, but it seems that the dikes themselves are less persistent than those of the other rock. The largest one indicated on the map is in the knoll 1 mile northeast of Round Mountain. In the Blue Mountains there are several diabase dikes from 2 to 4 feet wide, which have been noticed by prospectors and explored by means of small shafts. They are decomposed, and thus the soft rock is distinguished from the harder, dark augite-hornblende-gneiss in a manner which at once attracts the attention of the prospector.

North of Bunker Hill, in the gneiss near the Querida-Silver Cliff road, is a dike of an augitic rock which may have been a porphyritic diabase. It is now very much decomposed, and along its outcrop resembles iron-stained vein matter so much that several claims have been located on its course. In the Golden King claim, where the dike is 11 feet wide, a shaft was sunk until comparatively fresh rock was found. Augite in large bright-green grains and a little brown hornblende are the only constituents now remaining to indicate the former character of the rock.[1] Calcite replaces all other original minerals.

In the Grand Canyon of the Arkansas and in Grape Creek Canyon occur many black dikes, often only a foot or two in thickness, which traverse the reddish granites and gneisses in all directions. Some of these dikes, and presumably most of them, are diabase of the type occurring

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[1] The peculiar secondary growths of amphibole in this rock have been described in an article published in the American Journal of Science for May, 1890. The most notable product is a blue variety containing much iron and soda. It occurs both as an enlargement and as a replacement of the primary hornblende and augite.

near Silver Cliff. A coarse-grained dike 20 feet wide crosses the head of Antelope Creek and is shown for 2 or 3 miles.

It may be noted here that the same rock seems to have a wide distribution in the Front Range of Colorado, in dikes similar to those described. Thus Mr. W. B. Smith has observed them in the region about Devils Head (Platte Mountain); a broad dike extends from the Magnolia to the Ward mining district, in Boulder County, and the writer knows of three diabase dikes near Sugar Loaf Mountain, in the same district. An enstatite-bearing diabase, in narrow dikes, is almost the only eruptive known in the foothills west of Denver.

PERIDOTITE.

Peridotite is a group name for rocks free from feldspar and containing olivine as the essential constituent, which is usually accompanied by other strongly magnesian silicates. Varieties arise according to the minerals associated prominently with the olivine, those most commonly found being enstatite, hypersthene, diallage, augite, hornblende, and biotite. The rock to be described presents a rather unusual combination in that brown hornblende and hypersthene are developed in about equal prominence beside the olivine.

The peridotite of this district possesses but slight geographical importance. It occurs in a single small mass, cutting gneiss and granite, on the northern bank of Cottonwood Gulch, east of Querida, near the Hector and Mountain Boy mines. The body is of irregular shape, about 150 feet long, with a maximum width of 50 feet. Its contacts are not well exposed, and it is not represented on the map.

DESCRIPTION.

The rock is dark-brown or almost black in color, coarse-grained, and exhibits a dark hornblende, with brilliant cleavage faces, as the most conspicuous element. Besides the hornblende, brown lustrous biotite leaves are very distinct, and on close examination many reddish-brown grains, and others of greenish color, are seen. The former belong to hypersthene and the latter to olivine, the green color being due to serpentine of secondary origin. Much of the olivine is still in fresh condition. A very small quantity of a plagioclase rich in lime, together with apatite, sillimanite (?), and pyrrhotite, constitute the accessory elements of the rock.

The hornblende occurs in large individuals, sometimes an inch in diameter, and contains many of the smaller grains of hypersthene and olivine as inclusions. The interruption of the large cleavage surfaces by these inclusions produces the appearance called "luster-mottling" or the poikilitic structure. Biotite is developed in the same manner, its leaves partially inclosing many grains of earlier minerals. The hornblende is of the brown variety as a rule, but exhibits in some places a shading off into substance of a clear-green color. A similar change in color from brown to pale green is visible in some of the biotite leaves.[1]

The rock is exceedingly tough, and can be broken only by heavy sledge hammers.

This peridotite has the chemical composition given below, according to an analysis by L. G. Eakins:

Analysis of peridotite.

	Per cent.
SiO_2	46.03
Al_2O_3	9.27
Fe_2O_3	2.72
FeO	9.94
MnO	0.40
CaO	3.53
MgO	25.04
K_2O	0.87
Na_2O	1.48
H_2O	0.64
P_2O_5	0.17
	100.09

THE VOLCANIC SERIES.

The group of rocks now to be considered builds up the Rosita Hills, and some of its members appear upon the low surrounding ridges. The rocks are intimately related in occurrence, and from a geological standpoint they must be regarded as a series of products from the same volcanic or eruptive source. These rocks are found at practically the horizon of effusion; that is to say, most of them are found as surface masses and also as dikes, the observed relationship being due to faulting in a few instances only.

The eruptions of two of the rocks were plainly begun by explosive volcanic action producing much fragmental material. In one of these cases there were also many outpourings of thin fluid lava. But the other effusions were massive eruptions, which produced even-grained rocks almost identical with the dike forms.

The order of eruption can be clearly established for most of the types, and they will be described in their order, as follows:

Rosita andesite.
Bunker andesite.
Fairview diorite.
Bald Mountain dacite.
Rhyolite.
Pringle andesite.
Trachyte.
Bassick agglomerate.
Miscellaneous rocks.

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[1] A fuller description of this rock was given in the article already cited: Proc. Colorado Sci. Soc., Vol. II, 1887, p. 240.

ROSITA ANDESITE.

The earliest member of the series forming the Rosita Hills is a hornblende-mica-andesite containing locally a small amount of augite. The materials classified under this type are in large degree the product of explosive volcanic action, and they are now seen in a complex of predominantly fragmental rocks—breccia or tuffaceous matter—with bodies of massive texture irregularly intercalated among them. The chief occurrence is beneath and about the town of Rosita, whence the local name applied. Corresponding to its age and mechanical constitution, the Rosita andesite is now exposed chiefly in certain valleys and on the lower hill slopes adjacent, while the more massive rocks of later eruption form the prominent hills about it.

DESCRIPTION.

The field habit.—The complex of materials here included has been much more completely and uniformly decomposed than has the rock mass belonging to any other type of the region—a natural result of its mechanical constitution, relative position, and greater age, which have allowed a freer percolation of solvent waters, and for a greater length of time, than has been experienced by any other rock. It is now impossible to find outcrops of the Rosita andesite in fresh condition; all is somewhat decomposed, and much of it extremely so.

The massive rock commonly seen in exposures, or on dumps of mines and prospects, is reddish-brown or dark-purplish in tone, while the breccia is bluish-gray or pinkish, the fragments being as a rule lighter in shade than the cement. The finer, loosely aggregated, tuffaceous material is very much decomposed and of various shades. The fine mud flows revealed by tunnels or shafts are frequently dark red-brown in color. The bluish or purplish-gray tones are eminently characteristic of the Rosita breccia over the greater part of the area occupied, but it is sometimes bleached to light-gray shades.

In specimens of the massive and comparatively fresh rock, one sees many small feldspar crystals, brown mica flakes, and the outlines of the former hornblende prisms, now filled by dull yellowish-brown substance, all lying in a dense aphanitic groundmass generally exceeding the porphyritical crystals—the phenocrysts[1]—in amount.

Composition of the massive rock.—A microscopical study of material from massive flows and of fragments from breccias shows that hornblende was once very prominent in all, but that it suffered almost total destruction during or prior to the period of consolidation of the

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[1] The porphyritic structure is that due to the conspicuous development of certain crystals in contrast with the groundmass surrounding and holding them as a matrix. To avoid the awkward repetition of the expression "porphyritical crystals" in describing porphyritic rocks, J. P. Iddings has proposed (Bull. Philos. Soc. Washington, Vol. XI, 1889, p. 73) the term *phenocrysts* for the prominent crystals, in opposition to the groundmass. Such a word is very desirable as an equivalent of the German term "Einsprenglinge," and it has been commonly adopted by English and American petrographers.

groundmass, with the usual mixture of products, which by later agencies of ordinary decomposition have given way to calcite, quartz, and hydrated iron oxide. Only the hornblende outlines and remnants of the granular border are now visible in most cases. The biotite is similarly attacked, but less strongly, and its small leaves are often fresh within and surrounded by a border of magnetite grains which have not suffered greatly from late decomposition. The plagioclase crystals are shown by their optical properties to belong to oligoclase, and they have the common characteristics of development. Inclusions are comparatively rare in all the crystals.

The groundmass of the fresh rock was plainly composed in large degree of small feldspar microlites, with magnetite and probably augite. But whether a glassy base was present or not can not now be made out, for nothing but part of the feldspar microlites remains fresh, while secondary calcite and hydrated products from the destruction of iron minerals now obscure everything. A marked flow structure is rarely visible, and doubts may well be entertained as to the previous existence of a glassy base in any considerable amount.

Variations in the mineral composition of rocks referred to this type arise through the appearance in some of them of augite phenocrysts and the partial suppression of hornblende or biotite. The most pronounced augitic forms provisionally referred to the Rosita andesite come from small masses intruded into the breccia or tuff, and it is by no means certain that all of them belong to the complex in which they now appear. Structural variations in the rocks arise from occasional greater prominence of phenocrysts as opposed to groundmass. The extremes in either direction are the masses whose relationship is doubtful. They are very possibly irregular offshoots belonging either to the Bunker or to the Pringle types.

The breccia.—The brecciated forms of the Rosita andesite are more common than the massive, but grade directly into the latter. In many places the breccia is merely the massive rock shattered, the fragments retaining practically their original relative positions and the structure appearing distinctly only on weathered surfaces. Bands of fragmental material alternate irregularly with massive rock in places. As a rule the spaces between the larger fragments are filled mainly with small angular rock particles, and the actual matrix is very subordinate, and so decomposed and stained by iron oxide that its original nature is obscured. In the more homogeneous breccias the matrix is merely fine attrition matter.

Breccias of heterogeneous character, in which the fragments are not all of the same type, also occur. In some of these, granitic and gneissic blocks and particles are found, but none of eruptive rocks other than the Rosita andesite have been noticed. These breccias are closely related to the tuffaceous modifications.

The tuff.—Much of the Rosita rock exposed by prospects consists of fine, loosely aggregated matter containing very variable amounts of large subangular fragments, and among both the fine and the coarse there is often much gneiss. Such material crumbles readily, and is naturally much decomposed. It appears irregularly and without observable structural arrangement, and it seems to be an already solidified material, broken up by repeated volcanic action, and hence properly termed volcanic tuff.

Portions of the tuff are so uniformly fine-grained, with the appearance of having been transported or arranged by water, that they may be considered mud flows. These masses have such limited extent that they can not be sediments, except possibly of small pools, and by analogy with some of the later, distinct mud flows of the rhyolite eruptions one is led to regard them as fine ejected materials, gathered and swept into hollows by water which may have fallen at the time of the outburst.

OCCURRENCE AND DISTRIBUTION.

Mode of occurrence.—It is a necessary conclusion from the evidence given by the mechanical constitution of the masses belonging to the Rosita andesite that much of the material was erupted in a violent manner, and the character of the ejectamenta makes it a further natural deduction that there must have been a piling up of débris about the vent. However, if the Rosita andesite mass ever resembled a volcanic cone it was so modified before other eruptions took place that the original form can not now be made out. At present the rock appears occupying a depression, and no observed arrangement of materials indicates the location of the vent or vents from which it came.

The Rosita andesite, mainly in breccia form, is penetrated by the Humboldt mine at Rosita to a vertical depth of several hundred feet. On the adjacent slopes of Pringle Hill there are exposed 200 feet of additional tuff and breccia. The present outcrops of the rock are limited to comparatively low ground, the main areas being at the head of Rosita Creek and on the adjoining Dutch Flat. At the north end of Game Ridge a very little tuffaceous material rests on the gneiss under the trachyte, and gneiss also comes to the surface about 1 mile west of Rosita. The rock, therefore, seems to occupy a depression, although the slope of the old surface upon which it rests is unknown, and faults have evidently had something to do with lowering the area under Rosita relatively to that north of Game Ridge.

Area occupied.—By reference to the map it will be seen that the chief area of the Rosita andesite is in a connected mass along the eastern edge of the Rosita Hills. Beginning at the south, the rocks occupy the basin about the town, thence extend up Hungry Gulch, forming the southeastern slope of Mount Robinson, and over to the head of Leavenworth Gulch. Dutch Flat is underlain by this rock, here chiefly of fragmental character and resting on gneiss, as shown along the eastern border. The trachyte body south of Querida rests upon the Rosita breccia, in part at least, and on the low ridges east of Querida the tuffaceous material of the Rosita rock is probably mingled with corresponding fragments of the Bassick andesite, a sharp separation of the two in their present decomposed state being impossible.

Along the northern edge of the hills are indications that the Rosita tuffs extended over this area. Between the rhyolite and the gneiss, on several low ridges, occurs reddish fragmental material in slight thickness which seems properly to belong to the Rosita rock, and on the eastern slopes of Bunker Hill is massive breccia which is thought to be a part of the Rosita andesite mass. This question will come up again in discussing the relationship between the Rosita and Bunker types.

Distribution of textural modifications.—The distribution of the various rock forms—massive, brecciated, or tuffaceous—through the known mass of this eruption is very irregular, as a result of the manner of eruption, and this complexity has been increased by faults, which can be proved in numerous places, though the actual influence of particular ones or the amount of dislocation can not well be measured.

In areas of the Rosita andesite the texture of the underlying rock is in a measure indicated by the surface features of the ground, yet all the rock is soft and resists erosion less strongly than the other rocks. The more massive bodies, and especially such as were intruded into soft, crumbling matter as dikes, stand out as comparatively prominent outcrops, as on the lower eastern slopes of Pringle Hill. The slopes of much altered breccia or tuff are very smooth and gentle, and were it not for the dikes of trachyte and rhyolite which cross the areas of breccia the slopes of the hills about Rosita would be very uniform and smooth.

In the workings of the Humboldt mine, as far as can now be ascertained, there has been an irregular alternation of massive rock and solid breccia, with comparatively little loose tuff. Parts carrying granitic fragments were encountered here and there, but the lowest rock penetrated, at 700 feet vertically, is said by the superintendent, Mr. Thornton, to be as massive as any found higher in the shaft. It is possible that some of the lower breccia of this mine is shattered trachyte, very much altered. The shade of nearly all rock on the mine dump is the characteristic bluish-gray which betokens considerable decomposition. Massive rock was found in excavating for the vaults of the brewery at Rosita, and a ridge of rock harder than usual runs along the stream bank just west of the town.

The tuffaceous rocks of the complex seem dominant in the lower horizons, but they may appear also at any other, to judge by their occurrence in Plymouth and Pringle hills. Tunnels in Plymouth Hill, on the west and southwest faces, show strong development of fine-grained, mud-like material. The tuffaceous form, with a large amount of granite or gneiss in large fragments, and also as a fine sand and gravel, is usually found near the gneiss, as along Dutch Flat.

BUNKER ANDESITE.

The Rosita andesite was followed, after a period of unknown length, by a dark, fine-grained, porphyritic rock, in massive effusions, which now makes up a large part of the interior portion of the hills. This rock is also an andesite, but possessing characteristics of development demanding a separation from the earlier type.

DESCRIPTION.

The fresh rock.—Although perfectly fresh examples of this rock were not found, one can determine the original constitution much more nearly than in the case of the Rosita andeites. It is a dark, compact, porphyritic rock, containing many crystals of feldspar, augite, biotite, and hornblende in a dense, homogeneous-looking groundmass. Crystals of more than 3 or 4 mm. in length are rare, and the groundmass somewhat exceeds the phenocrysts in amount.

Among the feldspar crystals one can easily distinguish a few in each hand specimen which are larger and clearer than the rest, and are usually simple Carlsbad twins. These are orthoclase, while the smaller, dull-white crystals are plagioclase. In some rocks all the plagioclase seems to belong to the variety andesine; in others, oligoclase, probably associated with andesine, which is, however, the most plentiful in all cases.

The plagioclase crystals do not have that sharp definition as contrasted with the groundmass which usually characterizes porphyritic structure, and the reason for this, revealed by the microscope, is that there is commonly a border of orthoclase about the crystals, this border interlocking by an irregular line with the feldspar grains of the groundmass. This outer zone also carries as inclusions the other mineral particles found in the groundmass, and thus causes a shading off between crystals and groundmass. This border growth of orthoclase is still more prominent in the later Pringle andesite and in the augite-diorite, but in a narrow zone it is a seldom failing characteristic of the Bunker type.

Augite and hornblende occur in small prisms, the former pale-green in color and the latter brown. Biotite occurs in thick tablets. The order of importance seems to be, augite > biotite > hornblende, but differing somewhat locally, and all three together are usually less than plagioclase in amount. Magnetite is prominent in phenocrystic grains, apatite much less so. All the dark silicates were attacked and partially resorbed before consolidation of the rock, probably during crystallization of the groundmass after eruption. Hornblende and biotite yielded the usual product, a mixture of magnetite and augite grains, which replaces the crystals entirely in some cases and forms merely a narrow border in others. Where the destruction was nearly complete the former crystal outlines are lost and the relative amounts of these minerals present in the original rock can not be determined. Augite was simply eaten into, but seems to have been rendered more susceptible to later decomposing agents than either hornblende or biotite. It is thus often replaced by calcite and chlorite when the remnants of the other minerals are fresh.

The groundmass of the Bunker andesite is a fine-grained, holocrystalline mixture of feldspar, augite, magnetite, and quartz. It is sometimes unevenly granular, where crystallization was slow enough to allow feldspar to form microlites or small, stout crystals, and in this case quartz forms a scanty base for the feldspar. Irregular augite and minute magnetite grains are scattered throughout the mass.

Aside from the variations provided for in the above description, the Bunker andesite presents fewer marked deviations from the type than most of the Rosita rocks. A bunching of hornblende prisms in small clots or patches is locally seen.

The decomposed rock.—The Bunker andesite as seen in the field is usually of some shade of greenish gray, less commonly brown, and is in certain areas bleached to a light-gray or nearly white rock. The greenish color is mainly due to chlorite coming from augite. In such rocks the augite grains of the groundmass are destroyed, and the outlines of the larger crystals inclose a mixture of chlorite, calcite, and quartz. Hornblende and biotite may be fresh while augite is wholly decomposed.

In the bleached rock the tendency has been toward muscovitization or kaolinization of silicates and the removal of iron and lime in solution. This extreme decomposition of all the Rosita Hills rocks, as seen at some points, is the subject of special consideration at the close of this chapter.

OCCURRENCE AND DISTRIBUTION.

The Bunker andesite in one connected mass forms the greater part of the Rosita Hills, interrupted only by subordinate bodies of later rocks cutting through it. Although it can be regarded only as an extrusion, there has been nothing observed that gives any clue to the situation of the vents through which the magma reached the surface. There is no flow structure, and the irregular jointing affords no evidence as to the form of the cooling surface. The rock maintains a uniform massive structure throughout, and nothing was seen which indicated boundaries of materials from different sources.

The hills of this rock are smooth-sloped, with rounded forms, and in some instances (Bunker Hill, the Sugar Loaf, etc.) the conical shape is very marked, but this seems rather a characteristic of the entire group of hills than of those made up of any particular rock, and is probably due to conditions of erosion.

The typical Bunker andesite in fairly fresh condition occurs in Bunker Hill, the Sugar Loaf, Lookout Mountain, and adjoining ridges, and about Mount Fairview. The extensive decomposition of the rock in many places, as in Kankakee Hill, the area west of Mount Robinson, and on the western border of the hills, may have obscured features which would have thrown light upon the origin of this type.

FAIRVIEW DIORITE.

Both the Rosita and Bunker andesites are cut by dikes and irregular masses of augite-diorite, which is shown in typical form in Mount Fairview. This rock is one of the less important ones of the Rosita Hills, from a geological standpoint, but it presents some very puzzling and interesting problems to the petrologist. The numerous variations in structure and composition exhibited by this diorite give rise to facies, some of which are difficult to distinguish from other rocks, especially when appearing in regions of great decomposition, as is here often the case. For these reasons the outlines of the larger bodies of the rock given upon the map are not to be considered as accurate.

DESCRIPTION.

The type rock.—The form which represents the mean of the extremes to be found occurs in the projecting cliffs on the eastern slope of Mount Fairview, and also at several other places to be referred to. It is a dark, rather fine-grained but still distinctly granular rock, in which clear plagioclase grains specked by minute ore particles are prominent, in even mixture with dull-green augite grains and brown biotite flakes. Here and there one sees darker-green spots of serpentine, arising from the partial decomposition of olivine. It is rarely that any mineral grain reaches 0.5 cm. in diameter.

The rock is hard and tough, with clean fracture, and at the cliff mentioned is jointed quite regularly into rectangular blocks by horizontal and vertical planes.

Microscopical study shows that labradorite, in rudely tabular grains, is the chief constituent. Augite occurs in imperfect prismatic crystals and in smaller irregular grains. Biotite appears in irregular flakes, often grown about magnetite or augite as a partial fringe. Olivine is a subordinate constituent, and it is probably more correct to regard the rock as an olivine-bearing facies[1] than to consider this mineral an essential of the type. It does not appear in most of the specimens examined which are otherwise near the type.

It is in the relations of various minerals to one another that the peculiarity of this rock lies. All of them seem to have grown more or less contemporaneously, and hence have mutually interfered with one another in the development of characteristic crystal forms. Biotite, augite, and plagioclase interlock irregularly. Even magnetite and apatite did not finish their growth until near the end of the consolida-

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[1] By the "facies" of an eruptive rock are understood those marked modifications in structure or in composition which are sometimes found existing within a single eruptive body. The term is applied to variations from the prevalent type of a given rock mass.

tion. The plagioclase grew less rich in lime toward the close of its formation, producing a distinct zonal structure seen in polarized light, and after the elements for plagioclase gave out the growth of the same crystals continued by the addition of orthoclase, the latter mineral often filling up the interstices in that way rather than by assuming an independent development, as usually happens where a finely granular groundmass composed largely of orthoclase incloses phenocrysts of plagioclase. This result is doubtless due to consolidation at a steady and probably a slow rate, rather than to any peculiarity in the composition of the magma, for facies of different composition belonging to this rock still exhibit practically the same structure.

The relative amounts of augite, plagioclase, and orthoclase present in different parts of bodies of this rock produce marked varieties, or facies, now to be considered.

Facies of the Fairview diorite.—The most marked facies of the Fairview diorite are those arising from variations in chemical composition in different parts of the cooling magma—variatións which resulted in different mineral combinations rather than in structural modifications. On the southern slope of the hill next south of Mount Fairview is a local development of a rock composed mainly of augite and magnetite with but little feldspathic material. It is very dark and heavy, and occurs as a part of a dike-like offshoot from the larger Fairview body. On the southern slope of the hill west of Mount Fairview, near the gulch, is a very coarse-grained, slightly pinkish-gray rock, which represents an increase of the amount of labradorite at the expense of the orthoclase and augite. Near this variety and in parts of the Fairview mass one finds orthoclase gaining on plagioclase in amount, until it seems almost to predominate. Here the orthoclase often appears in independent irregular grains, although still occurring for the most part as extensions of the plagioclase crystals.

Simultaneously with the increase in orthoclase there is a tendency to a development of hornblende, which replaces both augite and biotite, for in such rocks there is much less biotite than in the normal rock, and the hornblende is found surrounding pale-green nuclei of augite, which had begun its growth, perhaps, before the magma had become so strongly differentiated into portions of varying composition.

Such variations occur all through the masses of Fairview diorite. It is impossible to detect many of them until the specimens collected have been microscopically examined, and, moreover, the transitions within the rock mass are often so gradual that sharp division lines can not be drawn. The facies mentioned are not visibly dependent on relations to contacts with other rocks, nor to form or size of the diorite mass at the point where they occur. In the chapter discussing the eruptive phenomena will be found some further details concerning these rocks, with some general conclusions as to their meaning.

Structural modifications.—In a few patches within the granular diorite mass a porphyritic structure has been noticed through a development of large plagioclase crystals. The rest of the rock in such cases is still like the normal diorite.

Approaching the contacts of the larger masses, or in narrow dikes, the rock often assumes a porphyritic structure by the prominence of a few plagioclase crystals and the suppression of the other elements. Microscopical examination of some of these dense rocks shows that all the ordinary constituent minerals are present in smaller and irregular grains. But plagioclase and all the iron-bearing minerals are often less abundant in these zones than in the mass of the rock, and orthoclase occasionally becomes the predominant mineral.

By a gathering of the small augite grains in clots a mottled appearance is produced, and it is common to find little clusters of orthoclase crystals in spots all through the dense, dark groundmass.

Vein phenomena.—In certain places in the Fairview diorite there are veins of coarse-grained, predominantly feldspathic material. These veins vary in width from less than an inch to several feet, and the character of the vein matter seems in a measure related to the thickness of the body. In a vein on the north side of the prominent cliff of olivine-bearing diorite on the east slope of Mount Fairview, a part of the material thrown out in sinking a shaft is a very coarse mixture of pink orthoclase and quartz, resembling Archean vein granite. Another part is a finer, more even-grained rock, which would be called aplitic granite if taken alone. The contact zone is a distinctly granular, slightly reddish matter, with some dark silicates, mainly hornblende. The rock cut by this vein is a dark, fresh-looking diorite, coarser-grained than the olivine rock of the cliff close by. On microscopical examination this coarser rock is found to be the hornblende-orthoclase facies of the diorite referred to above.

In various places there are small veins which resemble the contact zone of the large vein just described. In these the feldspar (orthoclase) is chiefly developed in stout crystals, and the quartz occurs in grains, filling spaces. There are usually some miarolitic cavities lined by crystals of both minerals.

The fine-grained rock near some of the contacts of the diorite is mottled by spots less than an inch across, caused by a development of groups of orthoclase crystals with interstitial quartz, corresponding very closely to the material of many of the thinner veins. These spots shade off gradually into the rock about them.

These veins have not been found in other rocks of the region, and they are thought to be related in origin to the various facies described, which result from differentiations of the magma through influences not yet understood. Much more extensive vein phenomena have been observed in Gunnison County in diorite, where there is positive evidence that the veins represent the final phase in the development of the rock which they seem to cut as later bodies.

A modification has been observed in two places which is allied to the veins described as regards mineral composition, but occurring as a banded contact zone. This rock is dense gray and has no basic constituents. It is composed of quartz and orthoclase feldspar, in irregular development as to size of grains and relative amounts in the different bands.

Unfortunately, neither outcrop shows the transition from this development to the diorite proper. One locality observed is in the gulch at the base of the hill west of Mount Fairview, and the other is at the south end of the diorite mass east of Rattlesnake Hill. The Rattlesnake dike of Pringle andesite apparently cuts through this contact zone, as a patch of it is seen on its south side.

OCCURRENCE AND DISTRIBUTION.

The diorite was not recognized as an independent rock type in the first season's investigation, being considered a granular equivalent of the Bunker andesite. On revisiting the district, after a study of the rocks had been made, the diorite masses were found to be practically independent, but it was still difficult to determine the outlines of the bodies with accuracy. This difficulty is due partly to the débris or soil covering several important contacts, partly to the extensive decomposition of both rocks in certain areas, and perhaps even more largely to the transition character of the contact zones in many places.

The bodies of augite-diorite represented on the map are all within the area of the Bunker andesite. Aside from these, however, there are two small dikes penetrating the Rosita andesite breccia on the northern slope of Pringle Hill. Trachyte is the only rock found distinctly cutting into diorite, but it is probable that if the contacts were clearly exposed the rhyolite dike west of Mount Fairview and the Pringle andesite dike east of Rattlesnake Hill would be found to be later than the adjacent bodies of diorite. On theoretical grounds it is deemed probable that the diorite closely followed the Bunker andesite in time, and that it may even represent the closing phase of the same eruptive period.

By reference to the map it will be seen that the largest diorite outcrops are those of Mount Fairview and of the hill to the westward. It is quite probable that these two bodies are united by a narrow arm, and also that the dike in Paris Hill is a branch from the Fairview body, but if so the junctions are covered with débris. The details of all these masses are much more complicated than is represented, for to map them accurately would require full exposure of the contacts and time to follow them out foot by foot.

East of Rattlesnake Hill is a diorite mass on the southern border of the exposed Bunker andesite area. The contacts of this mass are difficult to establish on account of débris. On the northern edge of the Robinson Plateau is a long, narrow dike of diorite, a part of which is fresh, while the greater part is very much decomposed.

On the western spur of Mount Robinson is a small mass of diorite which assumes porphyritic structure near its contacts, and is consequently difficult to distinguish from the Bunker andesite where both are much kaolinized. The two narrow dikes at the head of Leavenworth Gulch are probably offshoots from this mass.

BALD MOUNTAIN DACITE.

The southeastern portion of the Rosita Hills is characterized by a fine-grained quartz-bearing andesite—a dacite. The map represents the principal part of the area covered by the rock, although Bald Mountain, from which the type is named, is situated just beyond the eastern line of the map, about one-half mile south of Rosita. While the exact position of the rock in the sequence of eruption is not known, it is clearly later than the Rosita andesite, and it is cut by the rhyolite.

DESCRIPTION.

The typical rock is fine-grained, gray, porphyritic, containing many minute plagioclase crystals of 2 to 3 mm. in length, with biotite, hornblende, and augite, also in very small crystals, and a fine-grained, predominantly feldspathic groundmass. The constituents are, therefore, the same as in the Bunker andesite, but they are of different relative importance, the dark silicates and magnetite being here much more subordinate to the feldspar than in the Bunker rock, a result of a decrease in iron, lime, and magnesia and an increase in the percentage of silica. The two types seem much alike in the field, though the dacite is generally lighter in color, and is seen on close examination to be much more strongly feldspathic. A microscopical study of this rock shows that the feldspar crystals are nearly all andesine; a few may be oligoclase, but none of orthoclase occur. The andesine crystals have the usual tabular form and a characteristic twin structure resulting from a combination of the albite, Carlsbad, and pericline laws. They are fresh; a few of them contain minute devitrified inclusions, and the zonal structure commonly found in plagioclase of more basic andesites, arising from changing chemical composition during growth, is never prominent. Biotite and hornblende are always present, the former being generally the more important, and both suffered from resorbent action during the crystallization of the groundmass. Augite is not always present. All these minerals possess the usual characteristics. Large scattered grains of magnetite (phenocrysts) are distinguishable from minute grains of the same mineral in the groundmass.

The groundmass is of the composition and structure common in trachytic rocks, being chiefly composed of prismatic microlites of feldspar which, as in the Bunker andesite, have a cement of quartz, or more rarely of tridymite. There is but little augite, and quartz is often developed in larger independent grains. Opal and chalcedony are local developments in rocks which were slightly drusy in structure, the minute irregular pores in such cases being filled or lined by mammillary forms of these substances, sometimes in association with tridymite.

OCCURRENCE AND DISTRIBUTION.

In its mode of occurrence this dacite is very much like the Bunker andesite. It builds massive conical hills, without visible structural developments indicating place or manner of extrusions. It forms a single mass similar in characteristics to the larger one of the Bunker andesite. It is cut by various rhyolite bodies, as is described in the following chapter, and as indicated upon the map. The contact with the Rosita breccia is along the débris-covered slopes of the hills south of Rosita, and was not seen in any spot. The relationship of the two rocks seems indicated by what we know of the position of the breccia, and by the topography. It is assumed that the dacite overlies the breccia in the same manner as does the Bunker andesite, but it is not improbable that faulting has had something to do with bringing the rocks into the position they now hold.

The Bald Mountain dacite is practically confined to the area indicated upon the map, with a slight extension east and south. Three conical hills, whose western slopes extend into the mapped area, form the eastern limit, beyond which granites and gneisses appear. To the south the dacite is partly covered by rhyolite flows of small extent, and gneiss appears again beyond them.

RHYOLITE.

Rhyolite is by far the most variable rock of the region, and is also the most widely distributed type. Scarcely two outcrops over the entire field present identical rock structures. It appears in dikes, in eruptive channels of quite another character, in lava flows showing many varieties of material, and in fragmental surface masses which are spread over outlying ridges.

DESCRIPTION.

The account of the different forms of rhyolite may be prefaced by saying that they come from magmas consisting almost entirely of silica, alumina, the alkalies soda and potash, and water, the heavy metals being present in very small amounts. The great variations in products are therefore due to the conditions and agencies at work during the period of consolidation.

The massive rhyolite.—Only in certain dikes does the rhyolite appear in a mass of approximately uniform character throughout. The narrow dike in gneiss east of Querida is of a fine-grained, holocrystalline porphyry, showing only subordinate feldspar and smoky quartz crystals in a granular groundmass. Other small and distinct dikes occur in which the rhyolite consolidated as a holocrystalline porphyritic rock. Some of these, as in the western ridge of the White Hills, cut the fragmental surface material of earlier rhyolite eruptions, and the rock is a porphyry, with comparatively large orthoclase crystals and a granular groundmass.

West of Rattlesnake Hill a dike in gneiss exhibits a white rock with but very small phenocrysts of two feldspars and quartz in a groundmass which the microscope shows to be a rather coarse-grained intergrowth of quartz and orthoclase. This rhyolite is closely imitated by a part of the material found upon certain adjacent ridges as a surface flow, and showing a tendency to fluidal structure by arrangement of the crystals or by alternation with clearly banded rhyolite of different character.

The lava flows of the low ridges about the Rosita Hills are penetrated by many prospecting shafts, which frequently reveal almost homogeneous porphyritic rhyolite, in alternation with beds of the other structural modifications; and in the surface material forming the White Hills much of the fragmental rhyolite is of quite homogeneous crystalline rock.

Banded rhyolite.—In certain eruptive channels and in some parts of the surface flows there is developed a banding through slight differences in the products of crystallization in alternate layers. This form grades into portions where the results are more markedly different in character, as, for instance, where there is an alternation of spherulitic and massive layers. In the rhyolite that is quarried at the Geyser mine and in other claims near Silver Cliff and in the upper part of Round Mountain the rock is distinctly banded, the layers being often very thin and showing foldings and crumplings due to movements of the viscous lava. The entire mass is crystalline, but some layers are white, others gray or bluish, a contrast caused by slightly different groupings of feldspar and quartz or by unequal distribution of the minerals. On some of these structure planes are flat cavities lined by quartz crystals, with minute garnets or topaz prisms. These cracks or fissures are allied to the lithophysæ to be mentioned.

The greater part of the rhyolitic masses seen on the low ridges about the Rosita Hills is, however, made up of banded rock of very abruptly changing structure, testifying to a great succession of thin effusions. In many of the flows a development of spherulitic structure took place, frequently in several periods, producing most complicated growths of a structural form which is one of the most interesting and significant products of crystallization from molten magmas. Glassy rhyolite, as pitchstone, occurs in these mixed flows, and varying quantities of a residual glass are found in many of the spherulitic bands. The complexity of structural forms of rhyolite in these outlying ridges of the Rosita Hills will further appear from the descriptions of these localities in the succeeding chapter.

Rhyolitic breccia.—The character of much of the rhyolitic material forming the low ridges north, west, and south of the Hills is best expressed by the term "breccia." As shown in prospects and outcrops, it is often a hard rock, consisting of angular fragments of rhyolite, often of various textures and structures, which were not primarily associated together, and in many cases gneissic fragments are added to the mixture. The rocks shown in a single shallow prospect hole often present a great range in make-up, some containing much granite and gneiss and others none, while in lower horizons there is frequently found a marked admixture of red, decomposed andesitic débris, which was probably derived from the earlier fragmental surface covering of the Rosita andesite. The occurrence of semituffaceous deposits of that rock between gneiss and rhyolite to the north of the Rosita Hills has already been mentioned. By increasing fineness the breccia passes into beds more properly termed tuff.

Spherulitic rhyolite.—The term "spherulite" has been applied to almost every aggregate of one or more rock constituents possessing an approximately globular form or radiate arrangement. The bodies here referred to belong to the most important class of spherulites, namely, those which are peculiar structural forms of crystallization from a magma, and are specially common in rhyolitic lavas. They are produced when the composition and the conditions of consolidation favor the development of the feldspathic constituent in radiating needles rather than in the usual crystal grains. These favorable conditions are as yet imperfectly understood. Few localities in the world present these interesting forms of crystallization in such great variety and under circumstances so favorable for their study as the district which has been examined.

The large bowlders of the zone between the pitchstone and the banded rhyolite at Silver Cliff are spherulites, probably by far larger than any hitherto observed. They are complex, it is true, but each constitutes an independent sphere or lenticular body lying in pitchstone, and is in a comprehensive sense an individual spherulite. Many of these spherulites are 5 feet in diameter, and some have been measured that were more than 10 feet across. The largest are no more complex than associated ones measuring but 2 to 3 inches in diameter, and correspond in character to many composite forms which have been described from other localities.

In Pl. XXVIII is given a view of the gigantic spherulites exposed in a long, open cut on the Buffalo (?) claim, the dump of which is on the left hand of the view in Pl. XXXVI. The round, composite spherulites with wart-like excrescences, due to the latest growth of the complex, are seen at several points in the wall. Several near the center are especially well shown. In the foreground on the left hand is one of these spherulites more than 5 feet in diameter, which has been cut through by the excavation. The material in which these masses lie is mainly the white mixture of opaline silica and kaolin resulting from decomposition of the pitchstone, described further on. Beyond the largest spherulite and below the most distinct ones of the view there is shown some pitchstone traversed by smooth fissure planes.

LARGE SPHERULITES IN OPEN CUT NEAR SILVER CLIFF.

In the rhyolites of the Rosita Hills a development of distinct spherulites in pitchstone, or separable from the surrounding rock mass in rounded forms, is not rare, but the rule is to find that there has been a succession of radiate crystallizations which have interfered with each other, so that the normal rounded form is lost, though the radiate structure may be very plain. In these lavas the conditions favorable to these spherulitic growths were not continuous, but recurred after short intervals, causing a series of radiate crystallizations, each with detailed peculiarities. Sometimes a new growth became an extension of the preceding one, but frequently the older spherules exerted no influence upon the orientation of the new development and were simply surrounded by it.

Between a glass with a few round spherulites and a rock with a complex of interfering radiate growths, or a banded rhyolite with spherules in layers, there are all manner of intermediate stages to be found in the Rosita Hills. A small residuum of former vitreous matter is often seen between spherulites. This is commonly decomposed and replaced by quartz and kaolin.

While the megascopical complexity of these rocks is great, that appearing upon microscopical study is almost infinite. As ideas concerning the origin and even the constitution of such spherulites have been obscure, from the lack of suitable material for investigation, the writer has improved the opportunity here presented to make an extended study of the problems involved, the results of which have been published.[1]

In a few places the spherulites are hollow, the cavity being irregular and earlier than the fibrous growth of the shell. In other cases the development of concentric shells producing the lithophysal structure has been found in very subordinate development. The best instances of lithophysæ are in the main rhyolite sheet of Silver Cliff, in the zone of transition between the huge spherulites and the banded rhyolite. Topaz and garnet crystals are found in the concentric cavities of some of these lithophysæ.

Rhyolitic tuff.—The rhyolite eruptions of the Rosita Hills were plainly not all of one kind. Some seem to have been fissure effusions of very liquid lava, while others were decidedly explosive in character and occurred in channels which were repeatedly used and became thus very much like typical volcanic vents. Some of these channels are now visible, and they are filled with fragmental material peculiar to them and to their immediate vicinity. The best instance is in Wakefield Hill.

The material now occupying these explosive channels is white, straw-colored, or light yellowish-brown, consisting chiefly of much kaolinized, pumiceous or glassy fragments, in a matrix of similar but finer particles. With these fragments are others of massive rhyolite of various

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[1] Constitution and origin of spherulites in acid eruptive rocks: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 411-444.

textures and structures, often partly glassy or spherulitic, and also granitic débris, in fragments of all sizes, varying from the small grains of feldspar and quartz, mixed in with cement, to bowlders several feet in diameter. Another substance found sparingly through this kind of tuff is charcoal, in small fragments, testifying to the proximity of the surface at the time of these eruptions

The surface about these vents must have been covered by ejected materials similar to those now seen in the space of the channels themselves; but being loose and light, they were easily removed and are not now found in any great extent. They still cover a space southeast of Wakefield Hill, and doubtless many of the fragmental beds found on the low ridges about the hills are in part made up of the ejectamenta from such sources, rearranged and spread out by floods of water, in admixture with any other rocks which through their occurrence in loose fragments could be gathered together at the same time.

Distinct ash beds have not been found within the area of the map, but upon a low ridge on the southeast bank of Leavenworth Gulch, nearly 1 mile south of the map line, there are beds of a light reddish-brown, friable, gritty sand, which is almost wholly a glassy rhyolite ash. This bed lies just beyond the limit of the more massive rhyolite flows and breccias extending southwest from the Rosita Hills.

Rhyolitic mud deposits.—Among the masses of rhyolitic débris which have plainly been transported or arranged with the aid of water, and which are now shown in ever-changing constitution, by the numerous small outcrops and prospect holes on the outlying ridges of the Rosita Hills, there are some very compact, white or grayish, earthy deposits which can properly be designated rhyolitic mud. They are commonly so much kaolinized as to destroy the evidence of their character as ash beds, which some of them doubtless were at one time. Many of them are very irregularly bedded and contain small angular particles of granitic quartz and feldspar, or of reddish andesitic rocks. Others are perfectly stratified, with regular bedding, though perhaps occurring in the midst of beds of breccia, tuff, or even massive lava.

That such local deposits were formed in pools of water, collected here and there upon the uneven surface of the rhyolite, and that the material fell in showers of ashes or of powdered rock, ejected from some neighboring vent, seems strongly indicated by the well-preserved leaf impressions found in several places. Specimens collected at two localities were placed in the hands of Prof. Lester F. Ward, paleobotanist of the Survey, and were by him sent to Prof. Leo Lesquereux for identification. The following species were identified by Professor Lesquereux and the descriptions published along with those of other fossil plants from the National Museum.[1]

Arundo goepperti Heer.
Quercus crossii n. sp.
Ficus tiliæfolia Al. Br.
Andromeda liniarifolia n. sp.
Vaccinium coloradense n. sp.
Cratægus holmesii n. sp.
Sapindus angustifolius Lx.
Rhamnus goldianus Lx.

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[1] Proc. U. S. Nat. Mus., Vol. X, 1887.

Other imperfectly preserved leaves occur, and stems and charred particles of wood are abundant in similar materials in many places.

One of the localities where these leaves were obtained is close by the road from Silver Cliff to Querida, at a point a little east of north from Bunker Hill and south of the Golden King shaft. Here a shallow prospect hole passes through dense gray tuff containing the leaves into a mixed fragmental material, and at 3 or 4 feet from the surface strikes gneiss, which forms a rocky knoll close by to the northward. The other locality is near the end of one of the little ridges running westward from Rattlesnake Hill, the deposit here being very fine-grained and perfectly bedded, but in a thickness of only a few inches, between layers of coarser fragmental material. Other holes near by did not show such finely stratified material.

Pitchstone.—The enumeration of forms of the rhyolitic material will close with a description of the vitreous rocks which give evidence of the perfectly fluid condition in which a part of the magma reached the surface. Throughout the rhyolite masses of the Rosita Hills region there occur small bodies of glass. They frequently appear as contact zones of varying width, banded parallel to the walls and passing by spherulitic transition zones into the massive rock. In lava flows they appear as small portions which have solidified quickly, or in some cases they are plainly later dikes.

Scarcely two occurrences are alike, though all are similar in resembling pitchstone rather than obsidian. The luster is vitreous or resinous, the fracture uneven as a rule, and the color is red, yellow, green, brown, or black, as the case may be. There is sometimes a tendency to perlitic structure, and one or two show minute lithophysal pores.

Microscopical study shows in but few cases any considerable number of phenocrysts of feldspar, and the trichites and microlites common in such rocks are often very poorly developed. The appearance of small spherulites marks the most common form of transition to crystalline rock.

The only large body of pitchstone occurs at Silver Cliff. This rock is nearly black in the greater part of its exposures, but is locally red, yellow, or mottled. It contains a few microlites and trichites, enough to indicate a fluidal structure, but carries very few phenocrysts of feldspar. The details as to occurrence of this rock and its relation to the zone of enormous spherulites, as well as the remarkable decomposition to which it has been subject, will be found in the descriptive chapter.

OCCURRENCE AND DISTRIBUTION.

Dikes.—Fissures through which rhyolitic magmas came to the surface are found all through the Rosita Hills and on the valley slope to the westward. The character of the material filling them is usually very similar to that of neighboring flows, and thus accords with the idea that the surface at the time of eruption must have corresponded nearly to that of to-day. An exception to this rule is the dike in gneiss east of

Querida, near the eastern line of the map. The rock of this dike is a porphyry with a granular groundmass. It is known that the country east of the California fault has been elevated relative to the Rosita Hills, and so this occurrence is explained.

A branching irregular dike occurs in the knoll at the head of Hungry Gulch, north of Rosita. It cuts the Rosita breccia and presents varied brecciated and spherulitic material of a character seen in surface flows. A similar dike, now much altered and poorly exposed, appears on the south slope of Pocahontas Hill. The dikes of the district south of Rosita are very irregular, and present material almost identical with that of the neighboring surface flows.

The broad dike of Mount Robinson probably represents one of the important conduits through which the rhyolitic magmas ascended. It now forms the highest point of the eruptive hills, and the lavas issuing from it may have flowed northward, as well as eastward and southward, the directions now seeming most natural. That it was one of the main channels would seem to be also indicated by the fact that subsequent solfataric action was there very strong, changing much of the rhyolite into hard quartz-alunite-diaspore rock, described under decomposition products.

On the western edge of the hills is another broad dike extending from Knickerbocker Hill eastward toward Mount Fairview. This channel is mainly filled with brecciated material so kaolinized that recognition of the original rock structure is possible only in a few places.

Near Rattlesnake Hill, and on the north slopes of the hills, are narrow dikes in gneiss or earlier fragmental rhyolite. These are small, and must be deemed unimportant offshoots from the larger vents nearer the center of activity.

Volcanic channels.—A typical vent of explosive action is shown in Wakefield Hill, south of Rosita. The details concerning the structure of this locality will be found in the descriptive chapter, but it may be repeated here that the major part of this mass is volcanic agglomerate containing bits of charcoal and numerous fragments of granite and of massive rhyolite. Shafts sunk in this agglomerate show it to be no superficial coating, and it has been cut by several very irregular dikes of pitchstone and of spherulitic rhyolite, like adjacent surface flows. There have been several eruptions through one channel, the first being of violent character, a true volcanic outburst, which must have built up a cone of loose materials that were removed, possibly, before the massive lavas were poured out. Nothing of the volcanic cone now exists, but it is impossible to see how material like that shown in the mass of this hill could have been produced without such an accompanying result.

The quartz-alunite rock of Democrat Hill must be accepted as evidence that a channel of some kind existed beneath it. In the mine workings below the rhyolite is found to be much shattered, and where banded the bands are vertical or nearly so. These facts, together with surface flows immediately to the south, indicate strongly that one of the most important vents of rhyolitic magma was at this point. Its form is not known.

The fragmental rocks of the White Hills, near Silver Cliff, are in themselves evidence of a very important vent near by. But the revelations of the Geyser shaft, which has penetrated 2,100 feet into stratified lake beds of predominant rhyolitic matter, prove beyond a doubt that an explosive eruption of great magnitude took place in this vicinity. From the resemblance between the summit rock of Round Mountain and the banded flow at Silver Cliff one might assume the latter to have come from a channel under that mountain. The indications are strong that several eruptions took place through the vent at Round Mountain, but owing to the poor exposures of the lower slopes the nature of the probable connection between that vent and the fragmental beds to the westward is obscured.

Surface flows and fragmental deposits.—A glance at the map shows that the rhyolite flows and fragmental rocks occupying the low ridges southwest and north from the Rosita Hills are situated in such relation to certain of the dikes or channels mentioned that inferences as to their immediate sources seem natural. As a matter of fact, the variability in structure and composition displayed by the lava of the flows is so great that positive identification with the rock of particular isolated channels is scarcely possible.

The natural inference that the great portion of the rhyolite on the ridges southwest from the hills came from the Democrat Hill channel or the dike of Knickerbocker Hill is not opposed by any evidence. The flows of the section south of Rosita are practically identical with the material in the adjacent dikes. As to the rhyolite north of the hills, it is probable that a local source existed in the area between Bunker Hill and the Sugar Loaf, but it may have been derived from the large dike on Mount Robinson, or even from that of Democrat Hill, for it is plain that there has been great erosion both of andesite and of rhyolite. There are traces of rhyolite on Dutch Flat, and it is probable that surface flows and fragmental deposits connected with the Mount Robinson dike once existed on this side of the hills.

Westward from the Rosita Hills there is some rhyolite exposed, and there are abundant indications that the entire slope out as far as Round Mountain was once covered by material similar to that on the north and south of the hills. There is a series of scattered outcrops still left along a line between Knickerbocker Hill and Round Mountain.

PRINGLE ANDESITE.

The rhyolite eruptions of the Rosita Hills was followed by an andesite outbreak, the relative age being clearly shown by the dikes of the later rock, which are seen cutting the rhyolite. This andesite is a biotite-augite rock, resembling the Bunker type in the appearance of noticeable orthoclase phenocrysts and in the presence of some quartz. It is seen in dikes, in a small sheet resting on rhyolite, and in a larger mass, which must also be considered as a surface flow brought to its present surface relationship by faulting.

DESCRIPTION.

The surface flow.—The main mass of Pringle Hill and of the hill next westward is formed by a rock belonging to a single body of andesite. It is dark-gray, porphyritic in structure, with phenocrysts and groundmass in about equal amount. Biotite leaves are scattered through the mass and augite may be detected on close examination. Of the feldspar crystals, a small but distinctly noticeable number are glassy orthoclase tablets, slightly larger than the plagioclase, reaching a maximum length of about 1 cm. The groundmass seems distinctly granular, though its constituents can not be clearly recognized.

The microscope brings out the fact that a small amount of hornblende is sometimes present. Both augite and hornblende are much attacked. Augite occurs in prisms, which seem eaten into, and the matter filling the space of the augite which has been decomposed is mainly calcite, the same mineral which in some specimens examined practically replaces the entire crystal.

Of the feldspars, the triclinic, soda-lime species, which is oligoclase or andesine, is largely predominant over orthoclase, the latter constituting, however, one of the characteristic elements of the rock.

Biotite is more plentiful than augite in most cases, and is less attacked by the resorbing action than hornblende.

The groundmass is a coarse-grained mixture of feldspar microlites, augite, and magnetite, with in some cases a subordinate amount of quartz. The quartz may appear as a cement for feldspar microlites or in independent grains.

The dike rock.—The rock of the dikes, which vary in width from a few feet to 50 feet, is darker, a little finer grained, and with a rather more prominent groundmass than that of Pringle Hill. The constituents are the same, but titanite is frequently developed in microscopically visible crystals. By the formation of a zone of orthoclase about the plagioclase crystals, in the manner described for the Bunker andesite, the general resemblance between these two forms is much strengthened. This is found most marked in the coarser-grained, central portions of dikes.

OCCURRENCE AND DISTRIBUTION.

Owing to the strong general resemblance between the Pringle andesite as occurring in dikes and the Bunker andesite, it is impossible to be certain that no dikes of the former rock exist in the central part of the Rosita Hills. Unless a contact of very marked character should be found, the presence of the latter rock would never be suspected.

At various points on the northern and western slopes the outlying rhyolite sheets are cut by narrow dikes of a dark-brown andesite, some of which are shown upon the map. Although these dike rocks differ from the typical Pringle andesite in having microlitic groundmasses and by the abundance of glass inclusions in some of the feldspars, there seems to be no good reason for separating them from that type, to which they are related in time of eruption and in average composition. They are commonly biotite-augite rocks, with hornblende as an occasional constituent, and the glassy sanidines of the Pringle rock are wanting.

TRACHYTE.

The last member in the sequence of important eruptive rocks in the Rosita Hills was trachyte, and it is a fairly good representative of this type. It is found, analogous to the occurrence of the Pringle andesite, in two surface masses, and in a system of dikes which cut through all rocks in their path. The rock occurs in typical form in Game Ridge, and its dikes extend from Rosita westward through the hills to their western base.

DESCRIPTION.

The surface flows.—The trachyte of Game Ridge is a very light-gray porphyritic rock, whose most prominent constituent is sanidine, in glassy tablets and stouter crystals, much fissured, and usually 1 cm. or less in diameter, though sometimes reaching a length of 2 cm. Plagioclase occurs in smaller white crystals, upon the basal plane of which the distinguishing striation can be detected on close examination. The only dark silicate is biotite in minute leaves. Ore grains are often visible to the naked eye.

The groundmass, strongly predominant as a rule, is ashen gray in color, and while plainly feldspathic, it requires microscopical examination to make its detailed structure clear.

The study of thin sections shows the plagioclase to be oligoclase; the sanidine is very pure, and generally free from inclusions of consequence. Biotite has a ragged border, due to resorption, and apatite and zircon are present in very small quantities.

The groundmass is chiefly a granular aggregate of orthoclase grains, with some few prismatic forms, which are very probably a triclinic feldspar, though seldom affording means of determination. When microlitic forms are abundant their more or less distinctly parallel arrangement brings out a flow structure. Quartz is present in the groundmass in very subordinate amount. It occurs in small clusters of irregular grains, into which adjoining feldspar microlites project with sharp crystal outlines.

The trachyte of Game Ridge and Pocahontas Hill is, on the whole, one of the freshest rocks of the region, though still earlier than the period of at least a part of the ore deposition of the region, as proved by the ore bodies within the mass of the rock in the Nellie, the Polonia, and the Game Ridge mines.

The dike rocks.—The trachyte dikes of the Rosita Hills present an instance of the changes in outward appearance which are possible with a minimum of change in chemical composition. From the southern slope of the Game Ridge mass a train of nearly parallel dikes starts and runs north of west through Pringle Hill, across Leavenworth Gulch, Democrat Ridge, and the hill south of Mount Fairview. Beginning at the eastern end with a rock having plain resemblance to the trachyte of the adjoining mass, the rock of these dikes gradually changes to a dark, dense porphyry which has no resemblance to the normal type. The change consists in the reduction of the number and size of phenocrysts and an increase in the amount of groundmass, and, while plagioclase phenocrysts become more numerous than orthoclase, the groundmass grows darker and denser, so that in some of the narrow dikes the resultant rock is almost black, showing a number of white tablets of plagioclase and but a few of pink orthoclase. Such dikes seem to belong to a basic rock, and were at first supposed to be andesites. But the direct transition in continuous dikes, and the occurrence of contact zones of the dense, dark structure in dikes which in the center are nearer to the trachyte in appearance, prove the relationship of the smaller dikes from field study alone.

On microscopical study it is found that there is no essential difference in composition between extreme types. There is no augite or hornblende, and the dark color is found to be principally due to a dissemination of magnetite in extremely small particles throughout the granular groundmass. The grain of the groundmass sometimes allows of the determination of quartz, occurring nearly as in the Game Ridge rock. Chemical analysis of a dark dike rock shows practical identity in composition with the light-gray trachyte.

The decomposed dike trachyte, as seen in many places throughout the Rosita Hills, is very frequently characterized by fresh sanidine phenocrysts, which contrast very strongly with the more numerous but completely decomposed plagioclase crystals of dull-yellowish or white color.

OCCURRENCE AND DISTRIBUTION.

The Game Ridge mass.—The mass of trachyte which forms Game Ridge and extends westward, including Pocahontas Hill, is a block of a surface mass. The original contacts are shown in some places, but the California and other minor faults have done much to bring the mass into nearly the same horizon as the dikes along the southern slope. The detailed description of the local geology will make this plain.

The Julianna mass.—The flow of trachyte about the Julianna mine is not well enough exposed to show its true character very plainly. While gneiss comes to the surface at the Poorman and also near the Julianna, the workings of the Bullion shaft [13][1] of the latter claim show trachyte in considerable depth. There is apparently a combination of dike and sheet at the Julianna, while one of the Poorman shafts is sunk on a fault line, which aids in complicating matters.

The dikes.—Reference has been made to the parallel dikes cutting through the Rosita Hills. Those are the largest and most important, but smaller ones are seen in many places, and the decomposed rock found in débris of various places indicates the presence of many more. Only a few of the smaller dikes are shown on the map.

THE BASSICK AGGLOMERATE.

Bassick Hill and the greater part of Mount Tyndall are made up of a formation of peculiar character. It is a volcanic agglomerate, using this term in the strict sense given it by Sir A. Geikie in his Text-Book of Geology. A "volcanic agglomerate" is there defined as "a tumultuous assemblage of blocks of all sizes up to masses several yards in diameter, met with in the 'necks' or pipes of old volcanic orifices."[2] The Bassick agglomerate is conceived to occupy just such a volcanic channel as is implied in the definition given.

DESCRIPTION.

Mechanical constitution.—The rock mass here under discussion is throughout composed of fragments of different rock types, varying in size from blocks several feet in diameter to minute dust particles. The larger masses are subangular as a rule, though rounded ones may occasionally be observed, while the finer particles are more angular, and it is only in certain portions of the body that well-worn pebbles and bowlders occur.

These rock fragments are mingled together for the most part in quite irregular manner. On the outskirts of the mass a rude stratification occasionally appears, and there are portions which consist mainly of fine particles, but in general the larger blocks are scattered through a matrix of smaller fragments. Parts of the agglomerate are thus like tuff, others are almost breccia, and some portious resemble conglomerate as far as the shape of the fragments is concerned.

The old shaft of the Bassick mine has penetrated this agglomerate for 1,400 feet and has found the mass subject to these irregular changes in constitution throughout the extent explored. In the ridge south of Mount Tyndall a tunnel was driven for 750 feet in tuffaceous material inclosing a few large fragments, but a short distance above this tunnel the same tuffaceous material is crowded with subangular blocks of all sizes. No regular distribution of portions of similar character has been made out.

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[1] Numbers in brackets after names of mining claims correspond to the numbers of the claims on the map.

[2] Text-Book of Geology, London, 1885, p. 166.

Rocks of the agglomerate.—Andesites of several varieties make up by far the greater part of the Bassick agglomerate. The next most important rocks are granite and gneiss. Other distinct rock types are rare, and can seldom be identified, owing to extreme decomposition, but certain fragments of reddish andesite breccia and tuff can be confidently referred to the Rosita andesite. It is questionable whether the trachyte fragments which have been taken out of certain workings now abandoned were encountered as bowlders or as dikes, but the latter supposition is the much more plausible one.

A substance of comparative rarity but of much significance is charcoal, which has been found in surface materials and also in the workings of the Bassick mine.

With the exception of a very small, irregular dike of quite basic basalt—limburgite—no known portions of the filling of this channel have consolidated from fluid magmas in the place now occupied. All the fragments are of rocks already solidified at the time of the eruption which produced the present agglomerate. No bombs or scoriaceous fragments representing material thrown out in a semiplastic state have been as yet observed. Some of the finer-grained tuff, such as that encountered in the Centennial tunnel, may have been ash of more or less vitreous character originally, and, indeed, small fragments of the nature of lapilli may also be present locally, but the thorough decomposition which prevails has rendered it impossible to distinguish such materials, if they do exist, from the solid rock particles which plainly make up by far the greater part of the entire mass.

The andesitic rocks represented in the fragments of the agglomerate are of varieties closely allied to the Bunker, Rosita, and Pringle types. The Rosita breccia complex, and probably the Bunker andesite also, covered the site of the Bassick volcano at the time of its outburst; hence fragments of these rocks may be expected among the materials now filling the orifice. But the comparatively small amount of gneissic débris which has by any means found its way back into the channel made by repeated explosive action through that formation shows that the greater portion of the eruptive material must be considered as the product of this vent.

Among the fragments which have been examined microscopically no very marked types have been observed. Biotite, hornblende, and augite were often present as porphyritical crystals, and in many cases were subject to the same resorbent actions as in other magmas of the district. Sometimes biotite is found which has not been attacked in this way, and in these cases the plagioclase crystals usually carry abundant glass inclusions and the groundmass exhibits a fluidal structure. In general, the groundmass has suffered decomposition to an extent preventing a determination of its inner composition. While the feldspar microlites may indicate a flow structure, one can not tell whether the interstitial matter cooled as glass or not. The rarity of pronounced fluidal structure is itself, however, strong evidence that but a small amount of the ejected matter can have been partially molten. It is probable, from this fact and from the absence of surface flows which can be connected with this vent, that the volcanic activity displayed here was chiefly explosive. It was recurrent, and material consolidating in the vent was in subsequent eruptions broken up and ejected in angular particles.

Fragments of granite or of gneiss are nowhere abundant in the Bassick agglomerate, as seen upon the surface. In the workings of the Bassick mine, they have been encountered in varying quantity at all levels, but at the depth of 1,400 feet below the surface there is no apparent increase in the number of fragments.

The charcoal mentioned as a constituent of the agglomerate has been observed by the writer embedded in the rock of surface outcrops. According to Mr. L. R. Grabill, formerly assayer at the Bassick mine, charcoal "is occasionally, and at long intervals, found throughout the ore body and in the surrounding conglomerate from the surface down to the present depth, which is something over 800 feet."[1] The fragments noted by Mr. Grabill were in some cases several inches in length and showed the woody fiber distinctly. Some of the fragments had become silicified and occasionally impregnated with pyrite crystals. When not thus altered the wood glowed and slowly burned in a blowpipe flame. The occurrence of charcoal in this agglomerate is quite analogous to its appearance in the rhyolitic tuff or agglomerate of Wakefield Hill, which has already been described.

The cement.—As a rule the space between distinct fragments of the agglomerate is now occupied by earthy, light-colored matter, which is clearly much changed from its original condition. The pebbles and small fragments are generally kaolinized, or at least bleached, and the matrix is soft and crumbling, iron-stained, and shows ocher-lined cavities, due to removal of substance. In the mass of Bassick Hill there are few places where it is not at once plain that the finer, interstitial matter has been wholly decomposed. But on the slope of Mount Tyndall, near the rhyolite sheet, and in the prominent ridge north of the Mountain Boy mine [12], the rock is harder, the fragments are less decomposed than elsewhere, and are cemented by a dense, dark reddish-brown matter. These parts have the megascopical appearance of breccias cemented by eruptive material which has permeated them in a fluid condition. A careful microscopical study of the matrix of the breccias and tuffs shows, however, that it consists only of dust particles of the same rocks and minerals which occur in larger fragments. No substance of individual character, such as the crystallization of an injected magma would afford, can be identified. The dense and dark appearance is due to concentration of hydrous iron oxide, which has been apparently abstracted from the larger fragments, as they are uniformly lighter in color than the matrix and have quite generally lost their iron-bearing minerals, while they may be otherwise comparatively fresh.

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[1] On the peculiar features of the Bassick mine, by L. R. Grabill, Querida, Colorado: Trans. Am. Inst. Min. Eng., Vol. XI, 1883, p. 110.

GEOLOGICAL POSITION.

Surface relationships.—The important question as to the geological position of the Bassick agglomerate mass can not be answered at present as definitely as is desirable. In the descriptive chapter an enlarged map of the vicinity of Bassick Hill will be given and all the details of significance presented, but these data do not afford positive evidence as to the shape of the mass, nor as to the relationships to some of the surrounding rock bodies. The surface exposures show that the agglomerate occupies a small, nearly oval area at the present time, while from the evidence of the Bassick and the P & O mines it is clear that its boundary walls must descend very abruptly, in certain parts at least. These statements include almost everything that is positively known about the shape and size of the Bassick agglomerate mass. But from the character and arrangement of the materials of the agglomerate, and by deductions from the facts of similar occurrences elsewhere, one can draw certain further conclusions in regard to the form and limitations of the mass. These conclusions are, however, to be regarded as theoretical.

Comparison with volcanic necks of Scotland.—It is known that the orifice or eruptive channel of a volcano which has become extinct is choked up, near the surface, either by fragmental material falling back into it or by plugs of solid lava. A combination of the two kinds of material is common in most of the larger volcanic vents, where there have been several eruptions, but instances where the activity was purely explosive and where subsequent erosion has laid bare the filling of the channel seem comparatively rare, to judge from the literature on the subject. In the basin of the Firth of Forth, near Edinburgh, in Scotland, there is, however, an area of extinct volcanoes of Carboniferous age which are now exhibited in various stages of dissection by natural agents. Among these are some which present marked points of analogy with the Bassick mass as regards the kinds of material, the manner of its arrangement, and the form of the channel occupied.

The extinct volcanoes of this district have been described by Sir A. Geikie with great clearness.[1] Some of them have been so fully destroyed that the neck is seen in relation to the rocks which it pierces, and the superficial lava streams and tuff beds may have been entirely eroded away. The cross sections of the vents are usually circular or oval, with varying irregularities, and in size they range from a few yards to more than a mile in diameter. The filling of the vents is in numerous cases entirely fragmental, and the amount of country rock contained in the débris depends, according to Dr. Geikie, upon the character and extent of the eruptions through a given vent. Certain channels are almost wholly filled with fragments of the rock through

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[1] On the Carboniferous volcanic rocks of the basin of the Firth of Forth—their structure in the field and under the microscope: Trans. Royal Soc. Edinburgh, Vol. XXIX, 1880, p. 437.

which the orifice has been forced, others contain varying amounts of eruptive rock fragments, and some are almost free from débris of the country rock. The explosive force seems, therefore, to have preceded the column of molten matter, and if the latter did not reach the surface and the action was not renewed the channel became filled to some depth with fragments of the wall rock. In cases where the explosive action was repeated more and more eruptive rock was ejected, and in several cases cited the filling of the neck consists almost entirely of fragments of eruptives.

Charcoal in volcanic necks.—Although the necks described by Geikie usually contain some dikes or plugs of solid rock, he finds some of them filled wholly by an agglomerate which in mechanical constitution seems to be the counterpart of the Bassick mass. This resemblance even extends to the presence of charcoal and charred wood in the larger necks. To quote Geikie, "these woody fragments have not been found in the interstratified tuffs nor in the associated strata. They are specially characteristic of the necks. The trees from which they are derived grew, I believe, on the volcanic cones * * * ,"[1] and were destroyed by and mingled with the débris of a new outbreak, some portion of which fell or was washed back into the neck.

MISCELLANEOUS ROCKS.

Besides the important types that have been described, there are several rocks, for the most part occurring in small dikes, which are either independent eruptions or represent modifications of some leading type, the geological connection being no longer visible. These subordinate rocks will be dismissed with very brief mention.

MICA-DACITE.

Description.—The rock is light-gray, porphyritic by appearance of numerous small feldspar crystals and bronze biotite leaves in a strongly predominant feldspathic-looking groundmass. Some of the feldspars are glassy sanidine tablets, but the greater number are plagioclase, white in color, and in most cases these are muscovitized or kaolinized, or otherwise entirely decomposed. The biotite leaves are to a great extent replaced by the dark, granular resorption product in the manner described in other rocks above. Augite is not present. The groundmass is variously developed in different places. In its most coarsely crystalline form it consists of feldspar microlites interlocking in a very intricate manner, and of quartz developed in irregular grains of larger size. Tridymite occurs in a few cases. A spherulitic structure appears in one specimen, and many are brecciated. The reference of this rock to the quartz-bearing andesite, or dacites, is discussed in comparing the analyses of various types. The rock is related to rhyolite, trachyte, and common mica-andesite, but seems nevertheless to be more closely

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[1] Memoir cited, p. 471.

affiliated with dacite than with any other type. It is certainly an intermediate form.

Occurrence.—The most prominent body of mica-dacite occurs in a dike cutting the fragmental rhyolite covering of the low ridge north of Sugar Loaf and not far from the Querida-Silver Cliff road. Superficial deposits conceal it to a considerable extent, and the form given to the mass on the map is not accurate.

A narrow dike of this dacite cuts rhyolite at a point northeast of the Sugar Loaf, where Carolina Gulch turns abruptly to the north. Besides this dike there is one of an augite-andesite. Both are exposed beside the Querida-Silver Cliff road, and also in the rhyolite on the north bank of Carolina Gulch, close by.

The remaining occurrences of this dacite are on the southern side of the hills, near Rosita. One of them is at the point of the little ridge running south from the Rosita cemetery. Its relations are not exposed. The other mass cuts the rhyolite at the east end of Pennsylvania Hill, extends down into the bed of Rosita Creek, and forms a little knob on the northern bank. The outlines of this body are concealed by soil and débris, and it is omitted from the map. It is not known whether this rock had a surface distribution or not. From the rock structure one must infer that the portions of the dikes seen are near the level of the original surface, and probably some surface lavas were poured out from them, which have now been wholly destroyed.

BASALT: VARIETY LIMBURGITE.

Occurrence.—The only observed occurrence of this abnormal rock is on the ridge between Mount Tyndall and Bassick Hill, on the eastern side and near the top of the knoll nearest Mount Tyndall. The outcrop of the rock is a few feet across and is situated among the large fragments of andesite which are a part of the agglomerate at this point. No contact could be seen, and the form of the mass could not be surely determined, owing to the disintegration of the crumbling agglomerate in which the limburgite must be supposed to occur as an irregular dike.

In the vicinity of the outcrop the fine matrix of the agglomerate has been very thoroughly decomposed, and either appears earthy and kaolin-like or has been replaced by dense quartzose matter, which exhibits shrinkage cracks testifying to its former hydrous amorphous state. On the surface of some of the andesite fragments are groups of doubly terminated quartz crystals, and the feldspars of many andesitic fragments are entirely decomposed.

The great decomposition of the materials of the agglomerate is in strong contrast to the very fresh condition of the limburgite, whose perishable olivines are but slightly attacked. This fact affords clear evidence that the limburgite is more recent than the spring action which has permeated the Bassick agglomerate.

Description.—The rock is dense black in color, the only megascopic constituent being olivine, in minute glassy grains 1 mm. or less across, and often yellowish in tinge. These crystals are very numerous and lie in a groundmass of clear augite microlites and magnetite grains with a variable amount of colorless isotropic base between them. Olivine occurs only in distinct crystals, augite only in microlites, while the magnetite is of two periods of formation, the more important being with the augite in minute octahedra. A few flakes of reddish biotite, such as is common in basaltic rocks, minute apatite prisms, and in certain spots a few plagioclase microlites, are the only other minerals noticed.

The colorless base is isotropic except near fissures, and it is there apparently changed to a zeolitic substance, the nature of which could not be determined. Adjoining these fissures the olivine has been serpentinized, while in the solid rock the crystals seem often absolutely fresh.

Olivine, augite, and magnetite are thus the chief constituents of this singular rock, and it evidently belongs to the group of basaltic rocks free from feldspar which is called limburgite[1] by petrographers generally.

DECOMPOSITION PRODUCTS.

MODES OF DECOMPOSITION.

Nearly all of the eruptive rocks of the district have been subject at some point or other to extreme decomposition, yielding products so unlike the original rock that a thorough knowledge of the local geology is necessary before they can be referred to their proper formations. And in many places it is now impossible to draw boundary lines with satisfactory accuracy.

The fragmental rocks, such as the complex of tuffs and breccias belonging to the Rosita andesite, or the texturally similar rhyolite beds near Silver Cliff, have naturally been greatly decomposed by the surface waters circulating in them, for they occur principally in basins. In the Geyser shaft at Silver Cliff a great flow of water came in at several horizons, the discharge into the shaft having amounted to 100 gallons per minute at certain times, according to Superintendent Johnson.

The tuff is generally a white earthy rock whose feldspars are entirely decomposed, and here the product is chiefly kaolin. The Rosita breccia has been altered by a hydration of its constituents, the iron remaining as limonite or ocher, giving the characteristic red tones. Less of the iron and lime has been removed from this rock than from most of the others.

Much of the Bunker andesite occurring in the northern part of the hills and a large part of the Bald Mountain dacite have been partially decomposed by agencies which deposited calcite more or less abundantly

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[1] Rosenbusch, Mik. Phys. der massigen Gesteine, 1887, p. 811.

all through the rock, and also produced chlorite or epidote from augite and biotite. Such rocks are dull-green in color, but this process has never gone very far toward destroying the original character of the rock mass.

Another kind of decomposition has often obliterated the distinctive features of the several andesitic varieties, making the demarcation of the different bodies a matter of great difficulty. This is most commonly accomplished by a bleaching process which makes a light-colored or almost white mass out of the dark original, and even renders the distinction from similarly decomposed rhyolite no easy matter. This bleaching of the andesites is quite interesting as a special phenomenon of the region, and it has been carried much further here than in any other district of which the writer has knowledge.

There are two products of secondary processes that assume distinctive characters and form rock masses of some importance. One of these is the white siliceous clay resulting from decomposition of pitchstone at several localities; the other is the hard quartz-alunite rock of Democrat Hill and other localities, produced by the action of solfataric agents upon rhyolite. These rocks will be described in detail.

QUARTZ-ALUNITE ROCKS.[1]

Democrat Hill.—The prominent outcrops of the upper part of Democrat Hill, in the central-southern part of the Rosita Hills, are caused by a hard, somewhat porous rock, of light-pinkish or whitish color, weathering in roughly rounded masses very much like those often seen in granite exposures, and the rock itself has a strong resemblance to some granites, being composed of a mineral looking much like orthoclase, with a perfect cleavage and a pearly luster, occurring in irregular grains or rude tablets, with angular spaces between them, which are usually filled by small quartz grains. The latter mineral is also abundantly included in the former and causes a mottled or poikilitic structure on cleavage faces. Where the spaces between tablets are not entirely filled by quartz the rock has a porous structure. Angular cavities sometimes appear lined by imperfect hexagonal tabular crystals, which have usually been more or less attacked by solvents, so that their faces are rough and etched. No other minerals have been observed except kaolin as a local filling of small cavities.

The cleavable mineral of this rock has been determined by microscopical and chemical tests to be alunite, a hydrous sulphate of alumina and alkali, which is nearly insoluble in water and in common acids, excepting sulphuric acid, and possesses the hardness of fluorspar. The mineral crystallizes in the hexagonal system and the observed tablets are parallel to the basal plane, which is also the cleavage plane. Although possessing the durable characters necessary in rock constit-

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[1] These rocks were described by the writer in the American Journal of Science for June, 1891 (Vol. XLI, p. 466), in an article entitled "On alunite and diaspore from the Rosita Hills, Colorado."

uents, alunite is a rare mineral in this crystalline form, and this is the first known occurrence in this country.

Chemical analysis of massive material representative of the whole, from the cliffs above the Ben Eaton mine [18], afforded Mr. L. G. Eakins the following result:

Analysis of quartz-alunite rock from Democrat Hill.

	Per cent.	Molecular ratio.
SiO_2	65. 94	
Al_2O_3	12. 95	. 127=3. 26
Fe_2O_3	. 33	
FeO	. 07	
MnO	Trace.	
BaO	Trace.	
CaO	. 10	
MgO	. 05	
K_2O	2. 32	. 025 } =1. 13
Na_2O	1. 19	. 019 }
H_2O	4. 47	. 248 =6. 36
SO_3	12. 47	. 156 =4. 00
	99. 89	

The sulphuric acid, alumina, alkalies, and water are present very nearly in the proportions required for alunite, according to the formula $(KNa)_2O$, $3Al_2O_3$, $4SO_3$, $6H_2O$, leaving a slight excess of alumina and water for kaolin, which is undoubtedly present in small quantity. Thus the rock is practically two-thirds quartz and one-third alunite.

The entire mass of the quartz-alunite rock seems as pure as the specimen analyzed, though possibly in some places not seen there may be gradations into the rhyolite of which it is an alteration product. The outcrop caps the hill, and, as the mine workings underneath it show, the alunite does not seem to have been formed much below the level of the present rock exposures. This may represent the horizon near the surface at which sulphydric acid gas became oxydized.

Should there be any practical use for such a mineral it seems certain that a considerable quantity of it could be obtained at Democrat Hill. For centuries similar deposits in Italy and Hungary have served as sources for alum, which is obtained by slowly roasting the alunite and then extracting the alum with water.

Mount Robinson.—The rhyolite cutting the Rosita andesite of Mount Robinson has been altered in a large part of its course to a rock corresponding more or less closely to that of Democrat Hill. All the rugged crest of the mountain is due to this hard and unyielding mass, whereas the portion of the dike in the low ground to the northeast is but slightly altered in this way and has been easily eroded. At the western end of the dike, along the southern contact, and on the northeast slope of the mountain, the original character of the dike rock is clearly shown. It was spherulitic in some places, with a residual glass.

The altered rock of the crest of the mountain does not exhibit the same uniformity of composition that characterizes the Democrat Hill mass, and it is never so coarse grained as the latter. In many places, however, the rock is found to consist of quartz, with a variable amount of alunite in such small grains that it can not be surely recognized megascopically. Such masses are straw-colored or nearly white, with kaolin or ocher filling small cavities. At the eastern end of the crest of the mountain a very light-yellowish rock, determined microscopically to consist largely of quartz and alunite, was found by Mr. L. G. Eakins to have the chemical composition shown by the following analysis:

Analysis of quartz-alunite rock.

	Per cent.
SiO_2	69.67
Al_2O_3	13.72
CaO	.07
MgO	Trace.
K_2O	2.44
Na_2O	.34
H_2O	4.73
SO_3	9.27
	100.24

This indicates 24 per cent of alunite, assuming that all the sulphuric acid is so combined. There is a small residue of alumina and water for kaolinite and a very slight one of alkali; the remainder is quartz.

In the higher parts of the mountain ridge the rock is often more porous and at the same time distinctly quartzose, with small scales of a brilliantly glistening mineral. This has been found to be diaspore by chemical analysis and optical examination, as well as by the identity with distinct crystals occurring in certain cavities of the rock at the extreme western end of the crest. Alunite and diaspore evidently occur together in many places, but some of the porous rock near the summit of the mountain consists almost solely of quartz and diaspore. In thin sections the minerals can be readily distinguished through the stronger index of refraction of the diaspore, while cleavage flakes are a sure means of separation, owing to the difference in the crystal systems to which the species belong.

A specimen obtained at a prospect hole just west of the summit of the mountain has the following composition (L. G. Eakins):

Analysis of quartz-diaspore rock.

	Per cent.
SiO_2	76.22
TiO_2	.11
Al_2O_3	19.45
Fe_2O_3	Trace.
CaO	Trace.
Alkali	Trace.
SO_3	.29
P_2O_5	.13
H_2O	3.82
	100.02

There are thus but traces of other minerals than quartz and diaspore present in the mass. On long treatment with hydrofluoric acid a residue amounting to 17.79 per cent of the rock was obtained, and of this 84.67 per cent was alumina, 85.07 per cent being the theoretical amount in diaspore.

On the slope at the west end of the dike are many loose fragments with angular cavities containing diaspore crystals. Most of them are stout prisms of nearly hexagonal form with rounded terminations. The greater number are dull-white in color through kaolinization, and few present glistening faces. Some of the rhyolite at this place was spherulitic and in the cavities of the larger spherulites are also diaspore crystals.

On the slope toward Leavenworth Gulch some very brilliant minute crystals of diaspore were found, suitable for crystallographic measurements. These crystals were submitted to the late Dr. W. H. Melville for examination, and a note upon them accompanies the article describing the rock, which has been cited. The prominent faces in the vertical zone are the prism $\infty P\bar{2}$ (120) and the brachypinacoid (100), while the chief pyramid is $P\bar{2}$ (122); other faces, occurring in very subordinate development, are: ∞P (110), $\infty P\bar{\tfrac{4}{3}}$ (340), $\infty P\bar{\tfrac{7}{6}}$ (670), P (111), $P\bar{\infty}$ (011), and $P\breve{\infty}$ (101).

That part of the Mount Robinson rhyolite dike which adjoins Dutch Flat is often much kaolinized, but seldom shows marked development of alunite. But at the extreme northeast end of the dike, close beside the road from Querida to Rosita, at the Star claim, the rock plainly shows both alunite and diaspore. Chemical examination by Mr. Eakins showed the presence of 8.26 per cent of alunite and 4.5 per cent of diaspore in one specimen.

Alunite pseudomorphs.—At the northwestern end of Knickerbocker Hill, on the western border of the volcanic group, a shallow prospect shaft has been sunk in brecciated quartzose vein matter which is the alteration product of the Bunker andesite on a line of fissure. The shaft has long been abandoned and is now inaccessible, but its dump shows bluish quartz impregnated sparingly with sulphides and a small amount of breccia of much silicified andesite, the angular spaces between fragments being lined more or less abundantly with crystals, the greater part of which are quartz, while locally there are many tabular crystals deposited on the quartz. Kaolin and iron ocher are still later deposits.

The tabular crystals are dull-white, opaque, with rough faces, yet showing distinct crystal form. The faces are to be interpreted as unequally developed positive and negative rhombohedrons, combined with a dominant basal plane. In size these crystals average 0.5 cm. in width by a thickness of 0.5 mm. A measurement of the most perfect crystals with a hand goniometer shows approximate agreement with the angles of alunite. On fracturing crystals the core is sometimes found to be a glassy, colorless substance of irregular form, while the outer part, or the entire crystal in other cases, is a white granular aggregate. Microscopical examination shows the glassy core to be fresh alunite oriented in agreement with the crystal form, and the white granular substance to be an aggregate of small particles of the same mineral with no regular orientation as regards the crystal.

Several of the white crystals were carefully detached from the little quartz crystals upon which they were implanted and analyzed by Mr. L. G. Eakins, with this result:

Analysis of alunite pseudomorphs.

	Per cent.	Molecular ratio.
Al_2O_3	38.91	.381 = 3.42
K_2O	4.03	.113 = 1.01
Na_2O	4.32	
SO_3	35.91	.446 = 4.00
H_2O	13.03	.724 = 6.49
CaO	.35	
SiO_2	2.82	
MgO	Trace.	
	99.37	

The crystals are thus chemically proved to be alunite, with a small amount of quartz and kaolin as impurities, and it seems necessary to consider the occurrence as representing alunite pseudomorph after itself, doubtless with an intermediate substance, of which, however, no traces have been observed. In explanation of this remarkable occurrence, it may be assumed that the first crystals of alunite suffered decomposition to some substance in which possibly the bases were retained, and that during a second period of solfataric action this alteration product was reconverted into alunite, the protected cores of the original alunite being unable to influence the orientation of the new generation.

SILICEOUS CLAY.

Decomposition product of pitchstone.—The pitchstone of the main rhyolite flow at Silver Cliff has locally undergone a decomposition by which a very white clay-like substance has been produced. At the old surface quarry of the Boulder claim and in the new cut on the Buffalo [4] claim the relationship of the clay to the pitchstone can be clearly seen. These openings are in the zone of the pitchstone carrying the huge spherulites ("bowlders"), and the latter are often found lying in a soft, white or pinkish clay, but in many places the glassy rock is seen in all stages of decomposition.

The pitchstone is traversed by many fissures, and the decomposition proceeds from them, gradually replacing the glass. In the intermediate stages the mass crumbles into many small, angular pieces, which are dull-white without, but show a fresh glassy core on being broken open. When the decomposition is completed there is nothing to show the origin of the clay, for the pitchstone is free from crystals of feldspar or quartz, which would remain as a grit in the clay.

Besides the surface workings which have been mentioned, this clay containing the spherulites has been exposed by numerous small prospects, and occasionally by outcrops. The workings of the King of the Valley mine [3] are to a great extent in this material. It was also encountered in sinking the Geyser shaft, but the most extensive development of it is in the old Fleetwood tunnel, just west of the Geyser property.

In the Fleetwood tunnel the product of decomposition is a perfectly white, soft clay, possessing no grit, and only stained by some ocherous spots here and there. As found in the tunnel it forms a compact mass, which, on being taken out, appears in blocks bounded by smooth slickenside-like planes. On drying, it falls into impalpable powder, and it also falls apart on being placed in water.

This clay-like mass consists in reality of opaline or flocculent silica and kaolin. The two substances can not be distinguished in appearance, and there is no quartz present. Chemical analysis shows the clay from the Fleetwood tunnel to have the composition given under B, while the fresh Silver Cliff pitchstone from which it comes has that given in A. The analysis is by L. G. Eakins.

Analysis of pitchstone and its decomposition product.

	A.	B.
	Per cent.	*Per cent.*
SiO_2	71.56	71.71
Al_2O_3	13.10	12.36
Fe_2O_3	.66	1.10
FeO	.28	....
MnO	.16	.17
CaO	.74	1.11
MgO	.14	1.21
K_2O	4.06	.36
Na_2O	3.77	.17
H_2O	5.52	11.97
	99.99	100.16

Sixty-five per cent of the clay is opaline or hydrous silica, soluble in caustic alkali, and the residue has the composition of kaolin, with probably some talc, and a lime silicate of some kind, for there is no carbonic acid in the material. This clay-like matter evidently occurs locally, and it is a question to be settled by exploration as to how far it possesses the purity shown in the Fleetwood tunnel.

Pitchstone has been altered to this substance in a less degree at other places in the district. In Democrat Hill, the Ben Eaton [18] and Democrat mine tunnels have encountered spots where glassy rock has been so altered. On the west bank of the Leavenworth Gulch, just south of the map line, a tunnel has been run for more than 100 feet in a clay of white or pinkish color, clearly derived from pitchstone, as can be seen by crumbling remnants of the glass here and there in the clay.

MUSCOVITIZED ROCKS.

The bleached andesites of the Rosita Hills and some masses of trachyte and rhyolite show a strong development of muscovite from nearly every constituent. Biotite seems to pass directly into the colorless mica, which for a time contains included crystals of anatase in many cases. Hornblende also passes into muscovite, with iron minerals as accompaniments at first, but these soon disappear. Augite is rarely altered in this way. The lime-soda feldspars are replaced by a brilliantly polarizing aggregate of muscovite leaves, after the manner often seen in orthoclase, but the potash feldspar of these rocks, occurring in phenocrysts in the Bunker and Pringle andesites and in the trachyte, and forming the predominant mineral of the groundmass in nearly all types, is rarely much altered until the other minerals have been almost completely decomposed. This is especially noteworthy in the trachytes, where glassy sanidines are often seen in rocks whose plagioclase phenocrysts are entirely decomposed.

Magnetite disappears from the rocks contemporaneously with the muscovitization of the silicates. Pyrite is commonly sprinkled through the bleached rocks, and in certain cases it seems to be a direct replacement of magnetite.

Calcite is a very frequent associate of muscovite, sometimes replacing the plagioclase or augite phenocrysts, but is more commonly deposited in irregular grains in the groundmass. It is often entirely wanting, having been dissolved out in late stages of decomposition.

The observations above recounted indicate that the rocks have been subject to the action of waters containing alkaline carbonates, which have extracted the iron, lime, and magnesia and have left the alkalies and sometimes the lime in the form of calcite. Kaolin may have been produced in some cases, but none of the bleached rocks subjected to microscopical examination shows it in any considerable development.

The bleaching of the andesites of the Rosita Hills has in some districts extended through large masses of rock, but clear evidence is found on every hand that it proceeds from fissures which penetrate the rock in all directions. In the western part of the Robinson Plateau and in Pringle Hill one can observe many places where the bleached rock adjoining a small fissure shades off gradually into dark and comparatively fresh rock within a few feet.

The chemical change effected in this decomposition is illustrated by the following analyses, which corroborate the conclusions drawn from microscopical examination. Analysis I is of Bunker andesite from Lookout Mountain, in which augite, hornblende, and biotite are all nearly fresh. II is of Bunker andesite from the western part of the Robinson Plateau. It represents partially bleached rock adjoining a small fissure, where the decomposition has extended but a few inches on either side. III is of very much decomposed Bunker andesite from the ridge southwest of Knickerbocker Hill. The rock has some yellowish ocher on fissure planes and in spots through the mass, but the material analyzed was almost pure white. All these analyses are by L. G. Eakins.

Analyses of Bunker andesite and decomposition products.

	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	57.01	63.88	67.13
TiO_2	.27	....	.30
Al_2O_3	18.41	19.96	18.41
Fe_2O_3	3.69	2.21	.45
FeO	2.36	.57	.07
MnO	.21	Trace.	Trace.
CaO	4.29	2.03	.55
MgO	2.34	.58	.44
K_2O	3.72	3.88	5.28
Na_2O	4.95	4.19	4.17
H_2O	2.29	2.63	2.98
P_2O_5	.42	....	Trace.
	99.96	99.93	99.78

The rock II has lost its biotite and basic silicates and the magnetite has yielded to limonite, but the feldspars are not much attacked. In the rock yielding analysis III muscovitization of plagioclase is far advanced, while the former augite, hornblende, and biotite crystals can no longer be identified by their decomposition products.

It will be seen that iron, lime, and magnesia are almost completely extracted from the rocks by this decomposition; a little of the soda has also been removed, and the loss is accounted for almost entirely by an increase in silica and potash, alumina remaining constant. The increase in silica is represented by quartz grains.

This decomposition is in marked contrast to that producing the clay from pitchstone, by which the alkalies are removed, while the bases lime, magnesia, and iron increase in amount.

PLEISTOCENE DEPOSITS.

LAKE BEDS.

Of the two Pleistocene formations represented on the map, one is a local and unimportant lake-bed deposit, occurring east of the Blue Mountains. The lower beds are very white in color, fine-grained, and microscopical examination shows them to be tuffs consisting in large degree of glassy rhyolite dust, doubtless from some of the explosive eruptions near Silver Cliff or in the Rosita Hills, with a variable admixture of crystalline mineral particles. In some layers the glass particles are sharp-edged flakes traversed by many gas canals, but a very pure white, earthy-looking stratum, shown near the road and about on the map line, is chiefly made up of irregular isotropic grains, the character of which has not been made out. Some sharp splintery glass particles and some of feldspar are present. The analysis of this material, by Mr. L. G. Eakins, is as follows:

Analysis of lake-bed tuff.

	Per cent.
SiO_2	71.02
Al_2O_3	14.27
Fe_2O_3	1.22
CaO	1.38
MgO	Trace.
K_2O	3.97
Na_2O	2.28
H_2O	6.12
	100.26

This is very nearly the composition of the Silver Cliff pitchstone, and shows the rock to be a pure rhyolitic tuff.

The coarser beds following the tuffs are sandstones and conglomerates of mixed gneiss, granite, and volcanic rock fragments, with an abundant calcareous cement. Some of the finer-grained beds are practically sandy limestones, and an attempt has been made by some misguided person to burn them for quicklime.

ALLUVIUM.

The recent materials which cover the solid rock formations as a mantle have not been studied with a view to their differentiation. By far the greater part of the formations included under the general designation alluvium consist of gravels, washed down from the Rosita Hills and the higher areas of gneiss and granite, and the scanty soil formed upon them. This is usually termed "wash" by miners, and that name is used in this report as expressive and appropriate.

Wherever the wash is penetrated by shafts it is found to be a very irregular mixture of gravel and larger angular fragments of rocks known in the region. Its depth is always to be determined by experience, for there is much unevenness to the solid rock surface below.

In the extreme western corner of the district there is included a small area of the nearly level bottom land of the valley. This embraces nearly all lying below the 7,800-foot level, and it is for the most part cultivated as pasture or hay land.

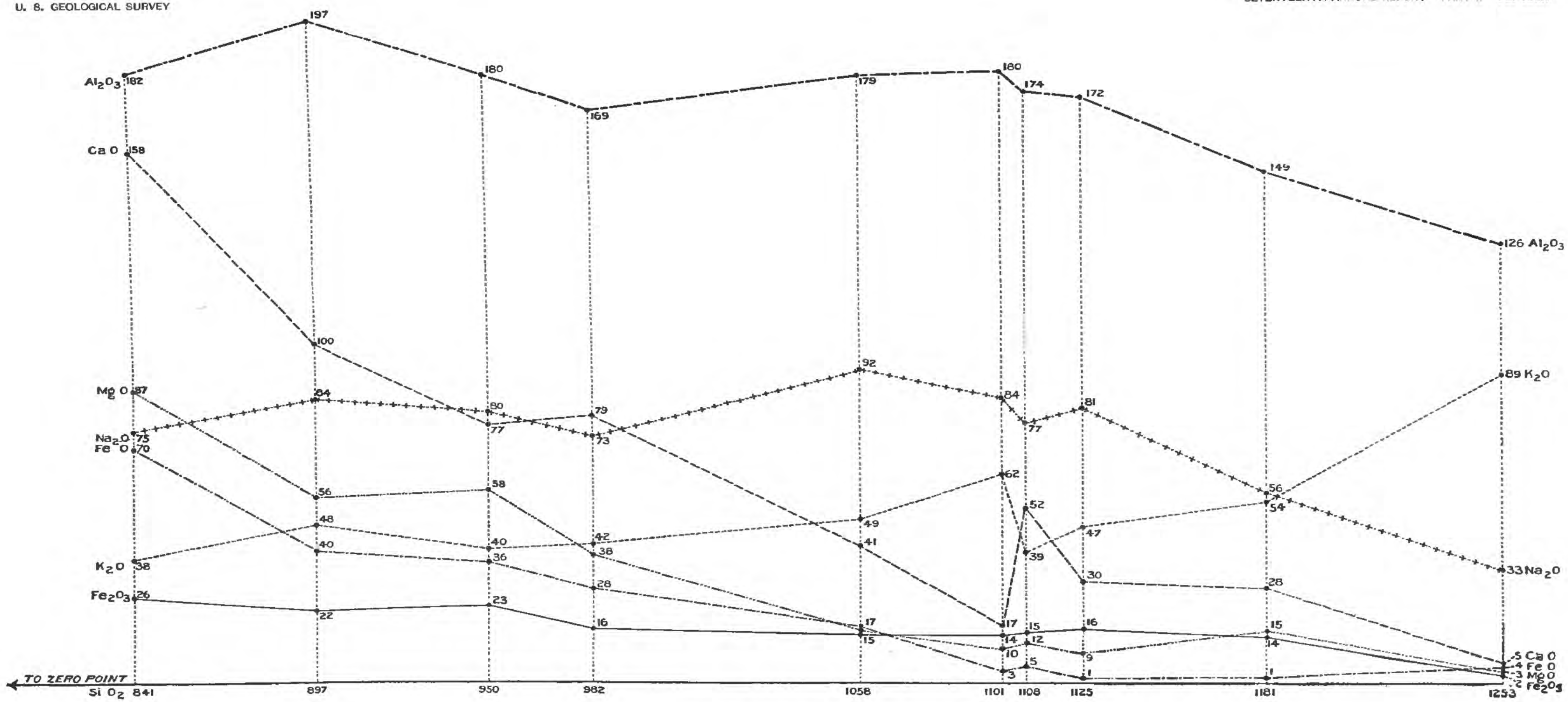
GENERAL DISCUSSION OF ROCKS.

CHEMICAL AND MINERALOGICAL COMPOSITION OF THE VOLCANIC ROCKS.

This group of rocks, representing a series of eruptions from a common source, affords an opportunity for instituting comparisons as to chemical and mineralogical composition and the structures developed. In the accompanying table are given chemical analyses of a number of the rocks, arranged in order of the silica percentages. These analyses were made by L. G. Eakins in the laboratories of the Survey in Denver and Washington.

Chemical analyses.

Name of rock.	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	CO_2.	P_2O_5.	Cl.	Totals.	Specific gravity.
Augite-diorite (olivine facies)...	50.47	0.51	18.73	4.19	4.92	0.11	8.82	3.48	3.56	4.62	0.58	Trace	0.10	Trace	100.09	2.870 at 32°C.
Augite-diorite (orthoclase facies)	53.80	0.43	20.13	3.57	2.63	0.29	5.60	2.26	4.49	5.20	0.90	......	0.56	......	99.86	2.768 at 34°C.
Bunker andesite	57.01	0.27	18.41	3.69	2.36	0.21	4.29	2.34	3.72	4.95	2.29	......	0.42	......	99.96	2.699 at 34°C.
Pringle andesite, Pringle Hill...	58.94	0.27	17.19	2.63	1.98	0.10	4.45	1.52	3.90	4.20	4.53	......	0.23	......	99.94	2.651 at 17.8°C.
Pringle andesite, dike	63.49	Trace	18.40	2.44	1.09	0.16	2.30	0.66	4.62	5.70	1.04	Trace	Trace	......	99.90	2.690 at 28°C.
Trachyte, Game Ridge..........	66.03	......	18.49	2.18	0.22	Trace	0 96	0.39	5.86	5.22	0.85	Trace	0.04	......	100.24	2.592 at 29°C.
Trachyte, dike.................	65.41	......	18.78	0.94	0.72	Trace	1.58	0.16	5.41	5.91	1.38	......	Trace	......	100.29	2.621 at 24°C.
Bald Mountain dacite...........	66.46	......	17.91	2.42	0.35	Trace	2.89	0.49	3.74	4.79	1.01	......	......	......	100.06	2.574 at 24°C.
Mica-dacite	67.49	......	17.76	2.54	0.08	Trace	1.67	0.35	4.40	5.03	0.52	......	Trace	......	99.84	2.563 at 24°C.
Rhyolite, Pennsylvania Hill	70.87	Trace	15.18	2.18	0.12	Trace	1.58	0.60	5.04	3.47	1.08	......	Trace	......	100.12	2.470 at 26°C.
Pitchstone	71.56	......	13.10	0.66	0.28	0.16	0.74	0.14	4.06	3.77	5.52	......	......	......	99.99	....
Pitchstone	73.11	......	13.16	0.62	0.23	0.14	0.54	0.19	5.10	2.85	4.05	......	......	......	99.99	....
Rhyolite, Round Mountain......	75.20	......	12.96	0.37	0.27	0.03	0.29	0.12	8.38	2.02	0.58	......	Trace	......	100.22	....
Rhyolite, Silver Cliff...........	75.39	Trace	13.65	0.38	0.18	0.14	0.51	0.15	6.81	1.84	1.13	......	Trace	......	100.18	2.560 at 15°C.



CHEMICAL COMPOSITION OF THE ROCKS OF THE ROSITA VOLCANO.

The analyses cover all the important types except the Rosita andesite, which is in all specimens obtained too far decomposed to afford typical material for analysis. Its composition was near that of the Bunker andesite, which followed it in time. In order to compare these analyses with reference to the mineralogical composition of the rocks, it is very helpful to express the analyses graphically in terms of the molecular proportions, by means of a system of ordinates and abscissas, as in Pl. XXIX.[1]

The range exhibited by these analyses is from a rock containing 50 per cent of silica to one with 75 per cent, while the increase in silica is necessarily accompanied by a decrease in nearly all the bases. The alumina is the strongest base in all the series, and does not exhibit any remarkable variations, so that the main interest centers in the monoxide bases which are to combine with the alumina and silica in forming the essential minerals of the rocks.

In the olivine-bearing diorite, lime and magnesia approach nearly to the alumina in strength, but they soon become less important than the soda. Taking the series as a whole, the alkalies retain more nearly a uniform quantitative position than any other constituents, and hence become more and more the controlling element as lime, iron, and magnesia sink to subordinate positions. Potash is really the most noteworthy base of the series, having a prominent position in all rocks and acquiring a marked predominance at the acid extreme. But three of the rhyolites are represented in the chart, the others analyzed being almost identical with the last two except in the relations of the alkalies.

Comparing the mineralogical development with the data of the diagram, we find that lime, soda, and potash, by the positions which they hold relative to the other bases, make the series as a whole a feldspathic series. In certain facies of the diorite alone is the feldspathic element subordinate. And in the development of the feldspars the critical point is the contest between lime and potash for the company of the soda. As a part of the lime goes into early crystallizations, in pyroxene or hornblende, potash eventually gains the ascendency and monoclinic or alkali feldspars become more prominent in the later phases of crystallization than the triclinic or lime-soda species. In all the rocks, from the orthoclastic facies of the diorite to the rhyolites,

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[1] The first use of this graphic method of comparing a set of rock analyses, of which the writer has knowledge, was by J. P. Iddings. ("The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park:" Bull. Philos. Soc. Washington, Vol. XI, 1890, p. 191.) In comparing the observed mineralogical constitution of a rock with the chemical composition of the original magma, it is necessary to deal with the molecular proportions of the constituents; and it is an aid to clear comprehension to express those proportions graphically. Especially in comparing a group of allied rocks is this method advantageous. The diagram is constructed on the direct basis of the figures obtained by dividing the percentages by molecular weights. It is found undesirable to simplify these figures, as in rhyolite the values of several bases are apt to be very low. All the bases may be legitimately compared with one another on the common basis of the silica. Referring to the diagram, it is seen that the origin of the silica abscissas is far to the left, but all that portion beyond the lowest silica value may be omitted, as the scale used is a constant one. Upon the ordinates raised from the points determined by the silica values are plotted the remaining constituents. The lines drawn between ordinates are simply for convenience in tracing the variations of each base.

the alkali feldspars are prominent constituents. Even in the Bunker andesite, and more characteristically in the Pringle andesite, phenocrysts of sanidine are prominent among the feldspars. It has not been proved by analyses that the monoclinic feldspars of these rocks contain soda, but the amount of plagioclase in the trachytes and rhyolites, at least, is clearly less than it would be were all the soda in those crystals; and moreover, nearly all analyses of sanidine of recent date show some, and often large, percentages of soda. Soda orthoclase represents the extreme of this development.

Comparing the two analyses of diorite, we see very plainly that the disappearance of the olivine and the prominence of orthoclase in the second rock are due to changes in the relative strength of magnesia and lime as compared with the alkalies.

Passing over points which will be clear to the intelligent examiner of the table and diagram, it is desired to call attention to the three rocks, trachyte, Bald Mountain dacite, and mica-dacite, as an illustration of the effectiveness of the diagram in revealing the importance of what seem at first glance to be slight differences in chemical composition of distinct rocks. These three types are readily distinguished, and would be held to be essentially different rocks by an inspection of the hand specimens. Percentage expression of the chemical composition shows them to differ only about 2 per cent in any of the bases. The chart shows most graphically how the differences in lime and potash, while slight, are sufficient under the circumstances to determine whether the rock is to be characterized by its alkali feldspar or by the soda-lime species. A consideration of the increased amount of orthoclase in the trachyte shows why that rock has an insignificant amount of free quartz, while the dacite, with but 0.43 per cent more silica, has quartz in much more marked amount. The third rock stands between the other two in everything but silica. It has some sanidines, but its true position is not accurately expressed, for its plagioclase crystals are much decomposed and the lime should be somewhat higher. This rock is intermediate between rhyolite, trachyte, and dacite. A rock between this mica-dacite and the typical rhyolite is the rhyolite of Pennsylvania Hill.

SEQUENCE OF MAGMAS.

The order of the eruptions of the Rosita volcano as regards the chemical composition of the magmas can be quite definitely made out for the more important types. The only uncertainty is among the older andesites, which are not widely different in composition. The order determined is: (1) Rosita andesite, (2) Bunker andesite, (3) Diorite, (4) Dacite, (5) Rhyolite, (6) Pringle andesite, (7) Trachyte. In the position of the rhyolite and trachyte lies the main feature which is unusual. The Pringle andesite, which so plainly cuts through acid rhyolite, is not where it would naturally come.

While each volcano or group of connected vents seems to have a law of its own as to the details of the sequence of magmas erupted, there is such connection between the observed sequences of certain cases and theories as to the origin of the magmas themselves, that a considerable literature dealing with this subject has grown up. The historical review of the question by Iddings[1] furnishes a good basis for the consideration of this problem in a district where the order of eruption is known. The sequence of the Rosita Hills corresponds in general to that first advocated by von Richthofen, and also found most common by Iddings, and upon which the latter bases a general theory of the differentiation of magmas.

According to von Richthofen[2] and Iddings,[3] the most common order of eruption for the magmas of a given district is for an intermediate or average magma to begin the series and to be followed by an alternation of more acid and more basic magmas. Thus andesites are, according to these authors, most commonly the first products in a series, and these are succeeded by trachyte, rhyolite, and basalt. In the variations through intermediate forms and in the recurrence of magmas allied to the first product lie the peculiarities of certain vents.

In the Rosita Hills, andesites of intermediate composition certainly began the series, and, as shown above, the later eruptions were all more acid than the first magmas. In the order dacite, rhyolite, Pringle andesite, and trachyte, for these later eruptions, there is certainly no progressive increase in acidity, and basic rocks are not known.

This latter statement needs qualification by reference to the one small dike as representing large bodies of very basic magmas, which, according to the prevalent theories of differentiation, must exist in the depths, though they may not have come to eruption. It must be mentioned that Brögger, Teall, and others believe in a different order of succession, beginning with the more basic magmas, while adopting the same general idea of differentiation that is held by Iddings.

As Brögger has pointed out, the order in which different magmas will be erupted at a given center must depend somewhat upon the degree of differentiation attained in the magma at the time of the first eruption. If we suppose, for sake of illustration, that decrease of pressure has caused liquefaction at some point in the depths where the material has the intermediate composition of an andesite, an immediately following eruption would produce the undifferentiated magma, and the succeeding eruptions would represent such differentiation products as might have been formed in the intervals of quiet. But if differentiation followed liquefaction, and a long period elapsed before the first eruption, the succession of materials would vary according to many circumstances, and the order thought by Brögger[4] to be most common,

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[1] The origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, p. 89.

[2] The Natural System of Volcanic Rocks, San Francisco, 1868.

[3] Loc. cit., p. 145.

[4] Die Eruptivgesteine des Kristianiagebietes, II Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, p. 180.

namely, a progression from basic to acid magmas, with probable return to a basic extreme at the close, might well occur under the conditions Brögger has assumed for the Christiania region in Norway.

In view of the multitude of variable conditions which must prevail in different regions, the recognized absence of a general law in the succession of lavas seems quite natural. The relation of periods of differentiation and eruption, the shape of the molten reservoir and the place and manner in which it is tapped, the nature of the eruptive act, and many other elements enter into this problem and make a variety of results certain. But with the accumulation of facts and the development of theories to explain them, we may hope to reach a far better understanding of these complicated relationships of igneous magmas than we now possess.

EVIDENCE OF DIFFERENTIATION.

As has been stated, the various magmas erupted from the Rosita volcano are such as might be expected under the current theory regarding the origin of magmas by differentiation from a nearly homogeneous common source. The series is not complete, but there is nothing in this fact necessarily antagonistic to the theory.

Stated briefly, the current theory alluded to is essentially as follows: *It is believed that the observed variations in the products of a volcano,* or of any connected series of eruptions, do not mean that there has always been this variation in the chemical composition of the matter at the loci from which the magmas came. On the contrary, the family resemblances and the observed relationships of the rocks from a given vent have been interpreted as evidence that they are parts of a former whole of practically homogeneous composition. The variations in the series are thought to have arisen through chemical and physical agencies, resulting in a relative concentration of the several chemical elements in different parts of the original molten mass. This process is called differentiation, and while the laws operating to produce it are as yet very imperfectly understood, it is clear that either differentiation in this broad sense is a fact or the part of the earth's interior from which volcanic magmas come has always been heterogeneous.

The rocks of the Rosita volcano are clearly a related group. In the diagram of Pl. XXIX it appears that the group as a whole is characterized by the high percentage of the combined alkalies, and potash in particular maintains a prominent place throughout.

In the sequence of eruption at the Rosita volcano the requirements of the differentiation theory are met as far as the succession is complete, and the limburgite of Bassick Hill is a very significant indication that the basic magmas, which must necessarily be produced if the rhyolitic and trachytic magmas are differentiation products from an intermediate one, really exist in depth but never came to eruption. Strikingly analogous to this is the occurrence observed by the writer at the

Cripple Creek volcano,[1] where many small dikes of feldspar and nepheline basalt appear as the latest eruption at a center where andesite began the series and the alkaline phonolitic magmas were quantitatively very prominent.

The acid and basic extremes of differentiation have been aptly called "complementary" by Brögger, and if the theory above stated is correct, it is plain that in both the Cripple Creek and the Rosita regions there must exist somewhere the basic complement to the large masses of highly alkaline magmas which came to eruption. The quantitatively insignificant dikes of basalt in the two regions seem sufficient to show the probable character of the basic residues, now no doubt consolidated as deep-seated bathyliths or in intrusive masses.

In most discussions of the problems of differentiation it is assumed that the process takes place in great depths, except in cases of certain dikes where a regular zonal arrangement of matter differing in composition has been observed, or in sheets where some of the heavier minerals have settled to the bottom. But the phenomena presented by the augite-diorite of the Rosita Hills suggest local segregation of bases at or near the present site of the rock and after crystallization had begun. The facts bearing upon this point will be reviewed.

Brief mention has been made of the peculiar variations in composition which have been observed within the mass of the augite-diorite. All through the masses of this rock there are patches or areas of more or less different chemical and mineralogical composition not arranged in any regular manner, which blend in most cases by gradual transitions with the normal or average rock. Oftentimes these various products are of much similarity in outward appearance, and a quite detailed field study would be necessary to show the extent to which the differences go and the characteristics of the transitions. The observations made are sufficient, however, to indicate some of the bearings of these modifications, and are very suggestive in several directions.

The augite-diorite is found only in the area of the Bunker andesite, with the exception of two small dikes which cut the Rosite breccia on the north slope of Pringle Hill. Its masses are easily recognized, but great difficulty was encountered in tracing their boundaries. As the essential differences between the diorite and the Bunker andesite were not known at the time of the main field work, the granular rock was considered simply as a modification of the andesite, and the desire to complete the survey of the region within a given time caused the abandonment of any attempt to outline the diorite masses. However, during a hasty visit to the region in 1888, the boundaries of some of the diorite masses were approximately determined, but still no sharp line of contact between the two rocks was found. In some places the rocks are separated by a zone 2 or 3 feet in width where the two seem

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[1] Geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, pp. 1-209.

to blend, and in the case of the dike cutting the hill south of Mount Fairview the border zone narrows to a few inches. On microscopical examination of the transition material, it is found to unite some of the characteristics of both rocks and to resemble certain areas within the andesite itself. These observations lead to the idea that the diorite is intimately related to the Bunker andesite in origin, and may be practically a phase of the consolidation of the large bodies of that magma.

This view of the diorite's origin is not necessarily opposed by the observation that the diorite cuts the Rosita andesite in sharply defined dikes, above mentioned. An occurrence of significant similarity has been observed by the writer in the Ruby Range of Gunnison County, Colo., where there is a remarkable channel through which at least two eruptions took place. After the earlier one the magma adjacent to the walls consolidated as a rather fine-grained diorite, densest near the walls and becoming coarser inward. Before the central portion of the mass became solid the second eruption took place. At this time fissures were formed, penetrating the outer diorite zone and extending far out into the surrounding Cretaceous shales. These fissures were filled by a magma which solidified as a coarse-grained granite-porphyry, with large orthoclase crystals. Where these fissures cut the outer diorite zone the rocks are sharply defined, but toward the center of the channel both merge gradually into the granular or locally porphyritic rock, which seems intermediate between granite and diorite, and which represents the final consolidation of the center. This interesting mass, with several phenomena allied to the facies development of the augite-diorite, will be described in a future publication.

The observations of 1888 showed that the augite-diorite was much more variable in composition than had been recognized at first, and it became evident that the olivine-bearing rock was itself a facies richer in magnesia than most of the forms. It appears from microscopical study of the rocks that nearly all kinds of concentration may be found in the varieties of this rock. Augite and magnetite make up the greater part of some specimens (not found in place), and while plagioclase feldspar is the strongly predominant mineral in some patches, orthoclase gains the ascendency in others. With increase of the latter, hornblende appears. Were chemical analyses made of all the facies of these masses they would show far greater variations than appear in the series of distinct rocks of the region.

The interesting question regarding the origin of these chemical variations is as to the time and place at which the magma acquired this character. If it came to its present site varying thus in composition, it is remarkable that other magmas of the volcano do not exhibit in some degree a similar complexity; and as the diorite magma must have ascended from great depths, it is difficult to conceive how the motion of the liquid mass can have failed to either obliterate differences or cause through shearing a banded or "Schlieren" structure. But if these observed differences originated after the magma came to rest, an extremely local phase of differentiation must be recognized, which is not explained by the considerations applied to the process as assumed to occur on a great scale in depths.

Examining the characteristics in development of the minerals, it is seen that the magma contained few and small crystal particles at the time of eruption, and whatever facies of the rock is examined there is a striking similarity in the development of the mineral grains of earliest formation. Thus, apatite appears in large prisms with a smoky core and clear outer zone, and also in minute clear needles. Now, in the older minerals, olivine, augite, and magnetite, penetrating or included apatite crystals are usually smoky, without the clear outer zone which is to be considered as contemporaneous in origin with the minute needles. Augite, magnetite, and biotite are intimately associated in all facies. Biotite is commonly intergrown with augite, its leaves being parallel to the clinopinacoid of the augite, or it often partially surrounds grains of magnetite as a fringe. That the magma contained a very small amount of crystallized material at eruption seems demonstrated by the further fact that whether the texture be coarse or fine all constituents vary alike. If it be coarse there are but few large particles of magnetite, augite, and biotite.

There are local concentrations of magnesia manifested in the appearance of olivine. Lime must be relatively very abundant in the facies rich in labradorite, while potash and higher silica are found in the orthoclastic facies, where quartz is sometimes seen. Heavier iron content is shown by the local richness in magnetite.

The gradation of one facies into another is gradual as a rule, and a banding such as might be due to arrangement by flow was not observed. The mottled or spotted appearance of some rocks, caused by the richness in feldspar of small areas, and the minute veining, with feldspathic minerals seen here and there, all testify to an extremely irregular distribution of the chemical elements of this mass in the small space occupied by this rock. The granitic vein which has been described is to be compared with the aplitic dikes so often observed in association with diorite masses.

The writer does not consider that definite conclusions can be drawn from present knowledge of the facies of this diorite body, but hopes that the statement of the observed relationships may prove of value.

CHAPTER III.

DESCRIPTIVE GEOLOGY.

INTRODUCTION.

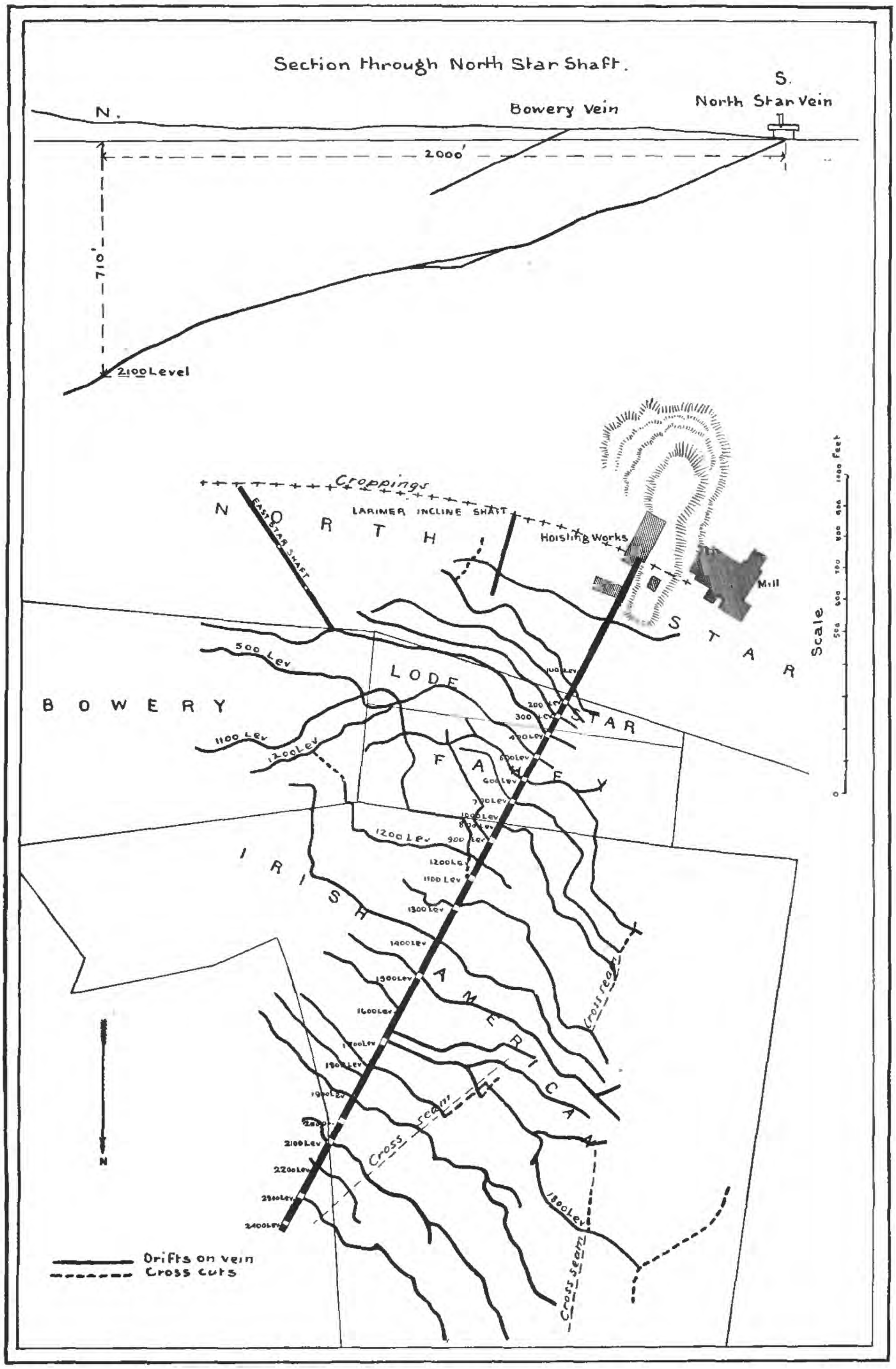
In presenting the details of geological structure, the writer will avail himself of three natural territorial subdivisions of the field, which owe their physical characteristics to the predominance in them of the ancient gneisses and granites, the volcanic, or the Pleistocene formations, respectively. It will be observed that the map represents a broad, irregular band of the first-named rocks stretching across the entire northern part of the area. South of this belt there is on the east a group of eruptive hills, on the west a gradually sloping surface covered by recent deposits, with the rhyolite masses of Round Mountain and the White Hills projecting above them.

The characteristic features of these three districts stand out with great distinctness and beauty as seen from the points along the western border of the Rosita Hills. To the westward the broad and gentle slopes of the Wet Mountain Valley seem wonderfully regular and smooth. The little ridges and knolls which the map brings out so clearly are scarcely distinguishable, and the White Hills appear as mere undulations of the surface. To the northwest the Blue Mountains and other similar groups rise like islands in a sea of which the more rugged hills and ridges to the eastward form the rocky shore. In marked contrast to either picture is that afforded by the eruptive hills and ridges near at hand on the east and south. They form a separate and distinct part of the landscape, a closely grouped series of rounded or even conical hills and smooth ridges, with but rarely a rough projecting outcrop of some quartzose decomposition product. Both the Rosita Hills and the valley slope are dotted and disfigured by the white dumps of hundreds of prospect shafts and tunnels, now for the most part abandoned.

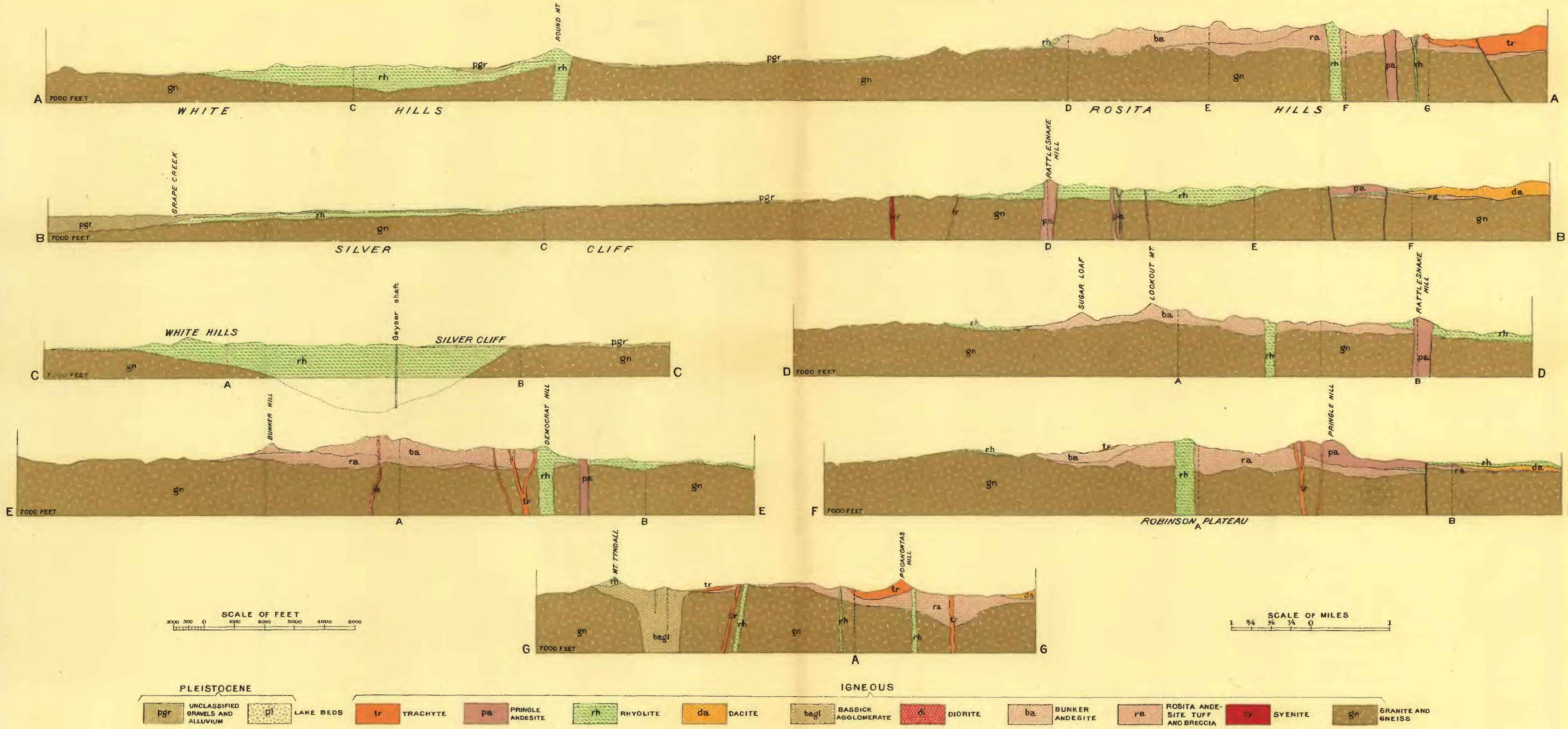
The geological details will be presented in sections corresponding to the areas above outlined, as follows:

I. Areas of gneiss and granite.
II. The Rosita Hills.
III. The valley slope.

VIEW OF THE ROSITA HILLS FROM NEAR THE GEYSER MINE, SILVER CLIFF.



MAP OF UNDERGROUND WORKS OF NORTH STAR MINE.



GEOLOGICAL SECTIONS THROUGH SILVER CLIFF AND THE ROSITA HILLS, COLO.

I. AREAS OF GNEISS AND GRANITE.

GENERAL DESCRIPTION.

Topographical features.—The surface features of the area occupied by gneiss and granite are chiefly due to its position relative to the Wet Mountain Valley. As was brought out in the introductory chapter, this depression has existed for a very long time in nearly its present form. The map exhibits a section across the rim of the valley which practically represents the character of the country for some miles to the northward.

In the view to be obtained from Lookout Mountain, on the western border of the Rosita Hills, the observer looking to the northwest sees a number of island-like masses, similar to the Blue Mountain group, though smaller, rising with very smooth lower slopes above the even floor of the valley. In the distance isolated hills of reddish gneiss or of granite rise higher and higher, now and then with connecting ridges, which also rise above the green slope of the valley. Turning more nearly northward, one looks along the edge of the valley trough, where the gentle slope rises against the rougher plateau country. It is there clearly seen that the low ridges between the Blue Mountains and Mount Herring, together with the adjoining country on the south, lie on the border of the valley. The tops of these ridges correspond so closely to the valley slope that they seem to form an almost unbroken surface, the gulches representing recent erosion being seldom distinguishable, and, as the map shows, a remnant of the Pleistocene deposits of the valley slopes is still found on the tops of the ridges.

The rougher and more elevated portion of the gneissic band of the map belongs to an elevated plateau whose surface is modified by many minor hills and valleys, but extends northward, with a general elevation of between 8,000 and 9,000 feet, for more than 20 miles, to the very edge of the Royal Gorge of the Arkansas, which cuts into it with a sheer depth of more than 2,000 feet. To the eastward this plateau rises somewhat, to descend in an abrupt manner about 3,000 feet to the level of the plains.

Southward from the area of the map the Wet Mountains rise more abruptly on the eastern side of the valley.

Structure.—The band of gneisses under discussion is not only a section across lines of topographical features, but also one obliquely across the strike of the formations represented. The prevalent strike of the masses of gneisses in the area of the map is between N. 40° E. and N. 75° E., and the dip is then northwesterly, varying from 40° to 90°, and being in most cases more than 60°. In the Blue Mountains the prevailing strike is seen along the southeastern base, east of the Bull Domingo mine, but northward it swings around with the ridges, and becomes N. 50° W. in some places near Dora. To the eastward the general NE. to SW. strike continues as far as the formation has been explored, viz, to the head of Antelope Creek, 3 miles southeast of Rosita.

To the northeast the strike gradually turns more nearly east to west, and there is at the same time a decrease in dip until the strata have an inclination of but a few degrees northward. Unless there is a complete inversion of the series, extending over a large area, the augite-gneiss of the Blue Mountains is near the summit of the section which has been examined, and the gneisses east of Querida are at the base. In regard to this question no positive evidence can be given.

DETAILED DESCRIPTION.

East of the Rosita Hills.—To the eastward of the district mapped is a treeless plateau ending in the uneven ground adjoining the Rosita Hills. Though dark hornblende or augite-gneisses appear locally, the predominant rock is reddish gneiss, with granite here and there. Through the surface disintegration of these rocks the ground is strewn with a reddish feldspathic gravel, which gives the general color tone, noticeable at a considerable distance. Adjoining the Game Ridge trachyte mass, along the California fault, is a dark augite-gneiss. The California and other shafts penetrate this, and it is well shown in a prominent knoll near the Horton [22]. The greater part of the surface north of Game Ridge toward Cottonwood Gulch is smooth and partially grassed over, the underlying gneiss being, however, frequently exposed in prospect shafts. At some points along the drain above the Poisoned Spring the surface material is quite deep, shafts 25 feet in depth failing to reach the solid rock.

The visible line between the gneiss and the Rosita andesite is determined by erosion. Several shafts near the eastern line of the eruptive rock have passed through tuffaceous material to the underlying gneiss at depths of less than 50 feet. The California fault causes the straight line between the Game Ridge trachyte and the gneiss.

Cottonwood and Tyndall gulches cut into the gneissic rocks sufficiently to give rather rough banks in many places, the ridges above being smooth, as a rule, through the surface disintegration of the gneiss and local wash deposits.

Dikes of eruptive rocks are occasionally found in this area, and their character indicates that where they correspond to rocks seen in the Rosita Hills they represent comparatively deep-seated parts, as if the California and other faults with the same relative displacement had raised the eastern country considerably. It seems as if the line of Tyndall Gulch, east of Mount Tyndall, might represent the course of such a fault, but no positive indications of a dislocation along this line were observed.

Very near the eastern line of the map, east of Querida, is a dike of a light-gray porphyry, an equivalent of the Rosita Hills rhyolite in composition, and also considered as such chronologically. It may be a distinct eruption, however. A small dike of black, fine-grained diabase was seen in gneiss on the western bank of Cottonwood Gulch, and just north of the Poisoned Spring are two dikes of fine, dark-green, much-altered rocks belonging undoubtedly to some of the andesites of the Rosita Hills, though their exact equivalence can not be stated. On the north bank of Cottonwood Gulch, near the Hector mine, is a small mass of peridotite, the relations of which are discussed in Chapter II. No other body of this rock has been found.

The broad, shallow basin east of Mount Tyndall is partly filled by wash, though the indications are that it is nowhere very deep. The gentle slopes adjoining are caused by gravel of disintegration.

North of the Rosita Hills.—A glance at the map shows that the gneissic area between Mount Herring and the Rosita Hills is much higher and more rugged than other portions. Tyndall Gulch, Silver Run, and their tributaries have steep banks, rising several hundred feet in some places, and the southern face of Mount Herring is 1,000 feet in height.

The rocks of these rough ridges are more nearly normal gneiss in composition than those of the eastern section. There is less of the reddish feldspathic variety, and more of a fine-grained biotite or hornblende gneiss. But this difference does not explain the topographical contrast, for these same gneisses run under the eruptives of the Rosita Hills and were degraded equally with other types by the agencies which formed the Wet Mountain Valley prior to the period of eruption.

Occasional syenite and diabase dikes occur in this area, but few of them are large enough to be represented upon the map. The dike of an augitic rock of peculiar character which cuts the gneiss in a northwest-southeast direction near the rhyolite boundary north of Bunker Hill, has been referred to in some detail in the preceding chapter.

On the northern slope of a low hill 1 mile southwest of Mount Herring a prospect shaft has revealed a curious formation the origin of which is by no means clear. The shaft is 20 feet deep, and is sunk on a vein which has solid walls of ordinary gneiss, the filling material being for the most part a curious conglomerate made up of some very round gneiss pebbles and a larger number of small, dull-green pebbles of what is seen on microscopical examination to be a very much decomposed eruptive rock carrying hornblende. The cement is also dull-green, and contains small particles of quartz and feldspar, though the larger portion is calcite, which is also the chief decomposition product of the eruptive pebbles. Some of the conglomerate is coarse, some fine, and at the bottom of the shaft is a fine, brown, sandy material which contains a large amount of brown mica. The surface does not show an extension of this material for more than a few feet from the shaft, and it seems like the filling of an open fissure or pot-hole by waterworn materials of some lake shore. New growths of the amphibole minerals in the cement of this conglomerate are among its features.[1]

Southeast of the Blue Mountains.—The low ridges lying along the edge of the valley depression described above are nearly denuded of their Pleistocene drift in the area between Mount Herring and the Blue Mountains, while to the southward the amount of superficial material gradually increases, so that east of Round Mountain the gneiss is shown only in scattered outcrops on banks of gulches. The gulches which cut into the gneiss and granite below the wash have in general rather rough banks, as they cut across the strike of the steeply dipping beds.

Red gneiss and masses of intrusive granite are especially abundant in this area. Some of the granite masses are almost conformable with the gneiss, while others cut across in dikes. There is very little dark gneiss in these ridges, and the red tone due to the microcline of the granite and gneiss is very marked.

Dikes of diabase occur in several places, but they are seldom traceable for considerable distances, owing to the superficial deposits.

The Blue Mountains and vicinity.—The cluster of ridges locally called the Blue Mountains form one of the island-like elevations above the valley slopes mentioned in the introductory sketch. The forms and relationships of this cluster of ridges are well shown by the map. The central ridge is the highest, and the other three practically branch off from its southern end. The curve in the eastern ridges is in a measure parallel to the changing strike of the gneisses.

The central ridge consists almost entirely of augite-gneiss of very massive texture, so that the banding is often not distinct in small masses. The western ridge is made of very similar rock, and the two eastern ridges also show much of the augite-gneiss, though more clearly banded and passing by various transitions into hornblendic or biotite gneisses. In the basin between the central and eastern ridges a layer of white gneiss was found without either augite or hornblende, and with silvery muscovite scales on certain planes. The débris slopes, which are partially grassed over, do not admit of very complete sections across the ridges. For this reason it is not certain that they are made up so exclusively of the augite-gneiss as they seem to be. Interstratified layers of other rocks are probably present throughout.

Marked features of the Blue Mountains are the granite dikes which traverse the gneiss and are very noticeable at a little distance. Syenite and diabase dikes seem more numerous here than elsewhere, but this may be due to the fact that these ridges were more carefully examined than other portions of the gneissic area.

One specially long syenite dike is represented on the map in each of the prominent ridges. The one cutting the two eastern ridges and

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[1] The interesting amphiboles of this occurrence and those of the Golden King dike have been described by the writer in the American Journal of Science, Vol. XXXIX, May, 1890, p. 359.

descending the southern slope almost to the rhyolite of the White Hills was traced along its whole course, excepting for the part in the valley between the ridges. Here it is covered by alluvium and débris for some little distance, but, as a dike appears on the southern ridge in the line of the one seen to the northward, there is no reason to doubt that they are parts of one dike. It has the characteristics assigned to the type in Chapter II.

A second noteworthy dike runs close to the Bull Domingo mine, and among the rounded rock fragments coated with ore which have come out of this mine are some of the syenite. This dike is seen back of the houses south of the mine buildings, and to the north its course can be easily traced up to and along the central ridge of the Blue Mountains, as indicated by the map. It may have greater extension to the north than was noticed, and to the south it disappears under wash, north of the rhyolite. The syenite dike cutting the western ridge is very sharply defined for the entire course represented by the map.

Diabase dikes, too small and short to be represented upon the map, appear particularly in the southern portion of the hills. None observed are more than 4 feet wide, and they are to be noticed only on close examination.

West of the Blue Mountains the surface is almost exactly that of the valley slope, but little ribs appear here and there which mark the outcrop of edges of dark gneissic strata, and small knolls are caused by more prominent outcrops. The ore of the iron mine at the end of a minor ridge west of the Bull Domingo is an augite-gneiss which has been altered so as to produce a black iron ore.

The hills rising near the map line west of the White Hills are a small island mass similar in composition to the Blue Mountains. Beyond them to the westward is the valley Pleistocene and then the bottom land. Granite dikes and one of syenite were observed in these hills. At their southern base, surrounded by Pleistocene, is a low oval outcrop of peculiar eruptive rock. It is a dense black hornblende-diorite-porphyry with partially cryptocrystalline groundmass, and in certain portions it contains many small particles of gneissic minerals, which have been partially fused by the eruptive magma. As no contact with the gneiss is visible, the form and extent of this body can not be made out.

Lake beds.—On the northern edge of the area covered by the map, at the eastern base of the Blue Mountains, is a small deposit of lake beds resting immediately on the gneiss and covered in many cases by the later Pleistocene wash and alluvium. The principal exposures are upon a low, smooth ridge, while remnants appear beneath the wash on several of the neighboring ridges. Much of the gulch erosion of the region has taken place since the deposition of the beds, and the composition of the lower strata proves that these first deposits at least belong to the period of rhyolitic eruptions in the adjoining volcanic district.

The upper part of the lake beds is rather coarse conglomerate with various eruptive rocks apparently from the Rosita Hills, and they seem likely to be of late origin. The formation has only a local importance in the region mapped, but investigations were not carried on far enough beyond the map limits to warrant an assertion that the lake may not have extended some distance to the northward.

The reference of these deposits to the Pleistocene is without definite evidence, as no fossils have been found in them.

II.—THE ROSITA HILLS.

GENERAL SKETCH.

The name Rosita Hills is here applied to the compact group of hills of volcanic origin situated in the southeastern portion of the region which has been studied. But few of them lie beyond the eastern and southern borders of the map, and they may be appropriately named after the little mining town occupying such a picturesque site in their midst, shown in Pl. XXXII.

The Rosita Hills are distinguished from the irregular gneissic hills of the adjoining region by their rounded contours and smooth, gradual slopes. Their general appearance as seen from the west is shown in Pl. XXXI. For purposes of description the outlying ridges are included in this section in so far as they are coated by remnants of lavas which came from the hills.

A small volcanic area.—The Rosita Hills are made up of a succession of eruptive rocks, the types of which have been described in the preceding chapter. While their surface distribution is brought out plainly upon the geological map, the structure of the complex can be but poorly expressed. It is quite clearly shown that the rhyolite surrounds the higher portions of the hills in sheets resting upon the gneiss, and some of the vents are shown in the interior, but the relations of the other types are merely indicated by the fact that dikes of one rock cut certain others.

The character and distribution of the rock types render it necessary to consider this complex as the result of long-continued volcanic activity; in fact, the whole may be said to constitute a volcano, the products of which have been in a predominant degree massive eruptions. True explosive volcanic action has prevailed at times, as will be demonstrated, but the records of those periods have been obliterated or covered up to a great extent, and the evidence concerning them is to be found only on careful study of the rocks produced.

A feature of this complex mass is that while the eruptive activity continued at intervals for a long time and a number of different rocks were poured out, the general physiography has remained approximately the same from period to period. Building up and wearing away have kept nearly even pace. There is no evidence that any of the eruptive masses ever extended far beyond their present limits, and the Rosita Hills thus present a remarkable instance of long-continued volcanic action on a comparatively small scale. Seldom has so limited an area witnessed such a series of eruptive acts. Were the rocks preserved in fresh condition it is probable that one might read in them a very complete epitome of volcanic history. But, unfortunately for the student of eruptive geology, the agencies so frequently attending the dying out of volcanic activity have long ago completed their work and destroyed much that is necessary to a clear understanding of the structure. The action of thermal waters has been very great, and gaseous exhalations played an important part at one time.

It has been thought best to sketch the history of the building up of the Rosita Hills as a whole, largely upon the basis of the rock characteristics which have been given, before proceeding to local descriptions, as the complicated structure of certain parts seems rather confusing without the guiding conception of a sequence of volcanic events with certain characteristics.

Rosita andesite eruption.—The sequence of eruptions in the region began with one of great violence. Somewhere near the site of Rosita there was an active volcano from which ashes and coarser fragmental materials were ejected in alternation with lava streams. The rock was a mica-hornblende-andesite, but the fragments vary so much in structure as to make it plain that several effusions took place, the products of which were shattered and mixed together during the successive violent phases of eruption. This material is represented on the geological map as "Rosita andesite."

Such action must have built up a small volcanic mountain, the finer fragments covering a considerable area about the vent, but this mountain was largely destroyed before the next eruption. Ashes to be referred to this period are found as red mud or tuff in slight thickness under the rhyolite flows west and north of the hills, but the more massive products are now limited to a comparatively small area on the eastern border of the hills. They evidently extend somewhat to the westward, under the massive Bunker andesite, but do not reappear on the western border at any point.

The vent or vents from which the Rosita andesite material issued are not indicated by any fact other than that the greatest known thickness and the most massive development of the type is in the immediate vicinity of the town of Rosita. Whether the main vent was here or whether a valley depression at this point was filled by the eruption can not be known. As will be explained at the conclusion of this sketch, there is a possibility that the Bassick neck represents the channel of eruption of the Rosita type, but there are weighty reasons against this conclusion.

The decomposing action of waters circulating in this broken material, situated below other rocks, has been great, and the original character of the ejectamenta has been correspondingly obscured. The tuffaceous or brecciated character of much of the rock and the occurrence of fragments of gneiss throughout is the chief evidence as to the nature of the eruption. The later explosive outbreaks of pronounced character during the rhyolitic period and the requirements of analogy with known volcanic areas are thought to justify the representation above made.

The massive Bunker andesite.—Following the Rosita andesite came the type which on the map and in the preceding description has been called the Bunker andesite. This rock carries porphyritical crystals of augite, biotite, and hornblende in varying development in different places, and the type is probably not far removed from the Rosita rock in chemical composition. It might, indeed, be very plausibly considered as the final product of the Rosita eruption so far as composition is concerned. The rock can be distinguished, however, and its occurrence suggests that it appeared after the interval during which the loose materials of the earlier eruption were to a great extent removed by erosion. Its uniformly massive character, too, indicates that a new phase in the manifestation of the volcanic energy should be recognized.

The Bunker andesite occurs in a single mass, forming the greater part of the northwestern half of the Rosita Hills group. Its primary contact lines are for the most part hidden by the later rhyolite. It must rest either upon gneiss or upon Rosita andesite, and its relation to the latter rock is shown opposite Mount Tyndall, where but a thin irregular remnant of the tuff comes between it and the gneiss.

The mass of Bunker andesite is clearly an effusion, and the eruptive act was a comparatively quiet welling out of the lava from fissures. The variations of the rock are not such, either in kind or distribution, as to indicate the source of the lava. In the gneissic area west of the Sugar Loaf are two narrow dikes of this rock, and it is but natural to assume the presence of other channels beneath the hills of to-day.

There is no vesicular rock, no vitreous portion, and no development of distinct flow structure in any part of this mass. The rock has a quite uniformly fine-grained holocrystalline porphyritic structure. While the former extent of this andesite is unknown, it must have built up a mountain of considerable height, with a surface crust possessing in greater degree the structural characteristics of lava streams, which was thick enough to procure for the inner parts of the mass the uniform conditions necessary for the production of the structure found. Denudation has exposed the core of the mass, and no portion of the original crust remains.

The Bald Mountain dacite eruption.—The massive hills south of Rosita are formed largely of a rock whose relation in time to the Bunker andesite can only be assumed. Both are later than the Rosita andesite and both are cut by rhyolite. As remarked above, the Bunker andesite is so closely related to the Rosita type that it may even be considered as the final product of the Rosita eruption, and it is therefore natural to assume the order here given. The rocks in question do not come in contact, and each is restricted to a single mass.

The dacite probably rests chiefly upon an eroded surface of Rosita andesite, but rhyolite flows conceal the greater part of the original contact line. The mass is like that of the Bunker andesite, in that its vent is not known and the rock structure does not give evidence as to the form or extent of the original eruption. The even holocrystalline structure shows that uniform conditions prevailed during its consolidation, and these were probably due to the protection afforded by the outer parts of the flow, now eroded away. There are no indications of explosive force attending the effusion of this magma.

The rhyolite outburst.—After the massive eruptions described above there was a return to violent volcanic activity, with a great change in the composition of the rock produced. Here for the first time one has an opportunity to examine the eruptive channels and their filling, as well as the surface lavas which issued from them. The surface flows of the rhyolite nearly surround the hills, while the vents are found at numerous points both in the center and on the lower slopes of the group.

In sketching the events of this period in the history of the Rosita Hills one is justified in making a direct comparison with modern volcanoes. The original vent of the Rosita andesite was probably plugged up with a solid core of Bunker andesite or of dacite, so that the explosive force of the new period found no one channel available for its manifestation, and, as seen in many volcanoes, the massive mountain was rent in numerous places and lava issued from fissures on its sides and at its base. There are rhyolite dikes shown by the map cutting the Bunker andesite, the Rosita andesite, or the dacite, as the case may be, while near Rattlesnake Hill is a vent in gneiss. Three miles away to the westward a new point of eruption was developed, presumably at the same time, and a large amount of material ejected, the remains of which constitute the Silver Cliff rhyolite plateau and Round Mountain.

The pre-rhyolite andesitic mountain had steep slopes, and doubtless rose much higher than the hills of to-day. This conclusion is necessary from the occurrence of the Mount Robinson and the Knickerbocker Hill dikes.

The character of the rhyolite eruption is more clearly indicated than is that of any other period. Extremely violent explosions made vents in several places, but especially in the dacite region south of Rosita.

The channel of Wakefield Hill is one of these orifices, and while the action through others may have been equally violent in the beginning, they are now more completely filled by the massive products of the later eruptions than is the case for the vents of the region about Rosita. As will be described in detail, the Wakefield Hill rhyolite body is a volcanic neck filled by an agglomerate with irregular dikes of massive rhyolite. Other vents near by are of similar character, while the Mount Robinson and other prominent dikes of the hills are occupied either by massive rhyolite or by material so decomposed that its original nature is not clearly shown.

The surface flows and beds of rhyolite corroborate the evidence of the channels. On the outlying ridges of the hills the complex of rhyolitic materials varies greatly in structure, but shows in general that ashes and tuffs predominate next to the gneisses and that the upper portions of the thicker bodies are usually massive. The variability in structure is largely due to the mingling of materials with somewhat different characteristics from different vents.

It is probable that the explosive action did more to destroy the volcanic mountain than the lava flows did to build it up. The rhyolite lava seems to have possessed much greater liquidity than others of this region, and it flowed down the steep slopes to build up the surrounding plain, thus modifying the general contour of the mountain.

As to the comparative duration of the rhyolite period, there is naturally but little evidence. The eruptions seem to have been numerous and from many vents, but may have followed each other in quick succession.

Period of the Pringle andesite.—Following the rhyolite outburst there was a return to previous conditions, both as to the quiet character of the eruption and as to the rock produced. The Pringle andesite is very much like the Bunker type in mineralogical composition and structure. Were it not for the intervening rhyolite outpouring these two andesites could hardly be separated so distinctly as to justify a reference to different periods; but the numerous sharply defined dikes of the Pringle type which cut through the rhyolite flows are positive proof as to the relative ages of the two andesites. The Pringle type is more siliceous than the Bunker rock, and can for the most part be distinguished as described in the preceding chapter.

In the interval between the close of the rhyolite eruption and the beginning of the new activity the mountain must have been considerably eroded, and on its southern side, at least, reduced to a form not far different from that of the present day. The proof of this is in the occurrence of andesite dikes cutting the rhyolite flows, while near by are surface masses of the same rock. As for the small andesite sheet north of Rattlesnake Hill, the possible unevenness of the rhyolite surface is probably sufficient to account for its occurrence at a level below the present exposures of the Rattlesnake dike. The fissure from which the lava of this sheet issued is apparently immediately below it. But for the andesite flow of Pringle Hill it is necessary to suppose a letting down, by faults, of this block of surface rock to explain its contiguity to the dike of the same material. As will be shown in the detailed description in this chapter, these faults are actually known on three sides of the mass. One has only to assume that the original rhyolite surface was but little above the level of the dikes as now seen to restore in imagination this slope of the hills at the time of the Pringle andesite eruption.

It must be considered probable that the Pringle andesite flow covered the entire southern slopes of the hills. The block of this sheet now preserved seems to occupy a basin in the soft Rosita breccia, and to this position, aided by the faulting mentioned, is due its escape from destruction.

The trachyte eruption.—The trachyte of the Rosita Hills was produced in what seems to have been the last important period of eruptive activity in this region. The rock is very different from the Pringle andesite in composition, but was erupted under very similar circumstances. It is seen in dikes which cut through every rock above mentioned except the dacite, and close by the dikes are surface bodies. These have, in this case also, been lowered somewhat by faulting with regard to the dikes seen, but on the whole it is clear that the surface upon which the trachyte was poured out was very much like the present eastern slope of the hills.

There are no surface masses of trachyte excepting on the eastern border of the eruptive district, but the dikes are found in all parts of the hills, and even on the lower slopes adjoining on the north, west, and south. These dikes prove that in all these parts the hills of this eruptive period must have risen somewhat higher than those of to-day.

Once more, the conditions attending the cooling of a magma were such as to produce in surface masses a holocrystalline texture showing but little evidence of motion during the period of its consolidation. The surface mass of trachyte must have been large, and the remnants now seen are probably parts which consolidated in depressions and were protected by a considerable thickness of lava.

The Bassick volcanic neck.—The Bassick vent has already been referred to in discussing the peculiar agglomerate now filling it. This vent has not been considered in sketching the series of eruptive periods, because of the uncertainty as to its relations. The rock which is predominant among the fragments of the agglomerate is an andesite closely allied to both the Rosita and Bunker types, but there is no special reason for concluding that this vent was formed during any one of the eruptive periods which have been described.

In a later portion of this chapter the evidence as to the age and relations of this channel is given at length, and it is only necessary to state in this place that the Bassick outburst seems more likely to have been the last than the first of the sequence. If the last eruption took place here, then the products have been entirely removed except in the immediate vicinity of the neck.

Period of decomposition.—The original constitution of the eruptive masses has not been the only factor in determining the forms resulting from erosion in the Rosita Hills. The rocks have been extensively decomposed in certain areas, with products varying so greatly in hardness and compactness that in one place they have offered much less and in another much greater resistance to degrading agencies than the original rocks.

The most common product of decomposition is the bleached rock which has been described in the foregoing chapter. Where boundary lines between rocks of similar structure run through such areas it is now impossible to draw them with accuracy. The line between the Bunker and Rosita andesites is thus rendered uncertain. Were it not for this softening of the Bunker andesite it is probable that the central portion of the Rosita Hills would rise much more prominently than it does at present.

Decomposition has, however, not always produced softer masses. The most rugged features of the hills are due to the projection of much decomposed rock. Thus the crest of Mount Robinson and the rough knobs of Democrat Hill and Knickerbocker Hill are caused by the alteration of rhyolite dikes. The products are a very hard, bluish quartzite or the rough alunite rock which has been described.

DETAILED DESCRIPTION.

AREA SOUTHEAST OF ROSITA CREEK.

This area is characterized by the hills of Bald Mountain dacite, a rock not occurring elsewhere in the region. It forms a series of round, smooth-sloped hills, broken here and there by the strongly contrasting rugged outcrops of rhyolite dikes. These hills make a chain extending south from Game Ridge, their summits being slightly beyond the eastern boundary of the map, and the low hills immediately south of the town of Rosita are of the same rock. Pennsylvania Hill and the succession of knolls on the east bank of Rosita Creek are of rhyolite flows, while in the immediate area drained by small tributaries of Rosita Creek the earlier dacite is broken through by dikes of rhyolite, and in the mass of Wakefield Hill there is shown the complex filling of a remarkable volcanic vent. There is no extensive decomposition of rock masses in this area, and, while a number of prospecting shafts have been sunk, there are very slight indications of ore.

Plymouth Hill.—Directly east of Rosita and south of Game Ridge is Plymouth Hill, the summit of which is just outside the map limits. Almost the entire mass of the hill is Rosita andesite in brecciated or tuffaceous form and much decomposed. At the western base of the hill, directly across from the Virginia shaft, is a dike of trachyte 30 feet wide, with some ore deposited on either side, on apparent minor planes of movement. This dike is undoubtedly connected with the main one to the westward. It can be followed toward the summit of the hill for a short distance only, as the middle slope of the hill is in part made up of mingled débris of trachyte and andesite, probably caused by landslides and extending to a depth of 20 or 30 feet in certain prospect holes.

On the very summit of the hill is a very small patch of trachyte. Débris and soil cover the contacts, but the rock resembles the Game Ridge mass so much more than any of the observed dike forms of trachyte that the body is regarded as most probably a remnant of the Game Ridge flow isolated by erosion. A shaft is sunk on the eastern border of the mass, but it was inaccessible at time of visit and no facts could be obtained regarding the relationship of the rocks encountered.

The Rosita andesite on the eastern slope of Plymouth Hill is mainly of tuffaceous character, of deep-red, purple, or lilac shades, and seldom shows the original rock structure distinctly. On the eastern slope, especially down near the base, the rock is different in character, apparently because it has undergone decomposition through different agencies from those which have ruled elsewhere. The rock here is apt to be tough and light in weight, and has the appearance usually described by the miners as "burnt." It has really undergone oxidation by heat rather than a hydration, as is common. Fragments ring when struck, and the breccia structure is often not visible until a fresh fracture is made. This character of the breccia is most pronounced down on the bank of Wilmer Creek, where the low ends of minor ridges are covered by a slight thickness of the eruptive resting on the gneisses, which here and there project through it. It is probable that the entire breccia mass of the Rosita andesite was thus altered and that this portion escaped a second decomposition.

Plymouth Hill is succeeded on the south by a similar elevation, which is made of Bald Mountain dacite, and the contact line with the Rosita andesite runs nearly through the little saddle between the two hills. From the saddle the contact between these two rocks apparently continues along the southern bank of the ravine running toward Rosita, and under the débris at the base of the hills south of the town. It has not been observed at any point.

Hills adjacent to Rosita on the south.—Adjoining the town of Rosita on the south are some low hills scantily covered by scrubby pines. They are made of Bald Mountain dacite, as shown by the fine débris scattered all over them and by occasional rock outcrops. The loose rock comes down to the edge of the town and conceals the contact with the Rosita andesite. From the known depth of the latter rock, as shown in the Humboldt mine, it is highly probable that it extends to the southward under the dacite of these hills, but no definite data bearing upon this point were obtained. In a later section it is suggested that a fault may run along the northern base of these hills and thus cause a sharp ending to the Rosita rock.

Bald Mountain.—Bald Mountain is the third and last hill in the row extending south from Game Ridge. It is considerably higher than Plymouth Hill or the intermediate knoll, rising 200 feet above the saddle connecting it with the latter. It has a nearly conical top and very smooth and steep slopes, excepting for the projection to be noticed.

The surface of the summit is covered by sherdy fragments of the dacite, of gray or pinkish color, which are quite fresh and ring sharply when struck with a hammer. Downward, the steep débris slopes become more and more covered by soil and a scanty vegetation. The descent on the east is even and steep for about 600 feet to Wilmer Creek, beyond which the plateau of gneiss and granite begins.

The dacite makes up the mass of the mountain except for some rhyolite dikes, the most prominent of which is seen on the southern face of the mountain. It appears 50 feet below the summit, in a knob-like projection, and below that point forms a jagged, abruptly descending wall 30 feet wide with nearly vertical sides. The rhyolite of this dike is a more or less porous, light-reddish rock, weathering in roughly rounded masses, bearing a very marked resemblance to red granite at a short distance. Within, the rock is irregularly porous, earthy in appearance, and stained by oxidation of the iron-ore particles. Locally it is indistinctly banded, the pores show indications of lithophysal structure, and parts are brecciated. The contact of this dike and the dacite is seen at the upper end of the outcrop, the rhyolite becoming dark, dense, and banded. From the upper end of the outcrop mentioned a smaller branch dike runs southwest down the slope, the banded contact being well shown.

On the northern slope of Bald Mountain, 125 feet below the summit, an incline tunnel affords a good exposure of a peculiar rhyolite dike whose outcrop is for the most part concealed by the slide rock. The tunnel runs 100 feet southwest into the mountain, with a dip of about 5°, following the incline of the nearly horizontal dike. The roof is the undulating contact surface of dacite, the walls are of rhyolite, and the lower contact is but little beneath the floor of the tunnel. Parallel to the upper wall of dacite is a band of dark, dense, felsitic rhyolite, 2 to 3 feet wide, containing spherulites several inches in diameter. These occur most abundantly in a zone 6 inches from the dacite. From the felsitic band to the floor of the tunnel the rhyolite is a black pitchstone. In some places a little pitchstone is seen on the upper contact. Just a few feet from the mouth of the tunnel a vertical cross contact with felsitic band parallel to it seems to indicate a terminal wall to this dike, which may be an offshoot from the larger one on the southern side, though of very different constitution.

Wakefield Hill.—One-half mile south of Rosita is a rather sharp-pointed hill which is one of the most interesting in the region from a geological standpoint. It has no local name and it is proposed to call it Wakefield Hill, after one of the men who investigated its peculiar formation by sinking shafts at its southern base in search of ore veins. The hill has a complex structure, which the comparatively simple representation of the map does not express. Instead of a single mass of rhyolite cutting through the dacite, there are a number of distinct bodies of massive rhyolite, which are irregular intrusions in a rhyolitic tuff occupying the greater part of the surface. The relationships of the various rhyolite bodies within the space are too complicated for expression upon the map, even if their boundaries were much more sharply defined by exposures than is the case.

The southern slope of the hill and the level divide on the map line present no solid rhyolite outcrops. The surface is strewn with fragments of massive rhyolite, and with a larger number of reddish granite bowlders. The fragments are subangular, or much rounded in the case of the granite. The lack of natural exposures on this slope is more than made good by what is revealed in the numerous prospect holes, which show that immediately below the surface there is a soft, white, or light-yellowish fragmental rhyolite rock, which has been described as tuff, and that in this tuff there are embedded fragments of granite, gneiss, or rhyolite. The latter are generally massive, but some are spherulitic or glassy, and they are often unlike any varieties known in place. The tuff proper seems to consist of very cellular, much kaolinized material of originally pumiceous character, in large and small fragments. Bits of charcoal and charred wood are also occasionally found in it. The gneissic and granitic material is scattered through the tuff in small angular particles, but frequently appears also in bowlders from less than 1 foot to more than 5 feet in diameter.

Shafts on the Broad Axe [31] and Bonanza [32] claims show that this tuff is not a mere surface deposit, the former being sunk about 300 feet in it without indication of any other formation. The Bonanza shaft is apparently sunk on a nearly vertical contact between the tuff and the Bald Mountain dacite on the west. This shaft was abandoned some years ago, but from one of the foremen employed during past work in the claim it was learned that the shaft was sunk on what seemed to be a "vein," with well-defined, smooth, undulating walls, with a strike a few degrees west of north. The shaft was sunk 150 feet, and a short drift was run north on the "vein." A slab an inch in thickness, said to have come from the west wall, was made of fine, mixed attrition material, and both sides were smooth, slickenside surfaces. The material of the dump is almost wholly tuff and its contained fragments. The conclusion that this shaft is sunk on a fault line is borne out by another shaft on the Bonanza claim, situated 100 feet higher, on the southwest slope of the hill and on the line of the supposed vein. This shaft shows near the surface a number of nearly parallel, undulating vertical fissures, with strike N. 5° W. The rock between them, as seen at the surface, seems to be crushed dacite for the most part, while the tuff adjoins on the east. Barite, quartz, etc., serve as filling to the fissures, but some movement has taken place since the barite deposition, as shown by slickenside surfaces on such vein matter. This fault, the displacement of which is unknown, is not traceable far north of the last-mentioned shaft. It apparently turns more to the west and leaves the contact between tuff and dacite, and, if continued, must pass near the eastern end of Pennsylvania Hill. It may have something to do with the complexity of structure at that point.

Tuffaceous material continues up to near the top of the hill. The summit is a rough knob-like point of light-reddish, massive or slightly porous rhyolite, like that of the prominent dike on Bald Mountain. On the northwest shoulder of the hill is another rough outcrop, presenting low cliffs to the southwest. Between this and the summit knob is a smooth surface from 50 to 100 feet wide, beneath which is a greenish, crackly glass with perlitic structure and containing many feldspar crystals. The northern slope of the hill is mostly smooth, with small outcrops of glassy rock or tuff. Granite fragments occur here again and extend down the ridge to the northwest. Spherulitic rhyolite appears in places down this arm, and apparently occurs as an interrupted dike running toward Pennsylvania Hill.

The northeastern arm of the Wakefield Hill rhyolite mass is comparatively narrow, but exhibits all kinds of material from the dark glass seen on the contact with the dacite to spherulitic and massive forms, and these in irregular relationship to tuff, even here carrying some gneissic material. Dacite approaches to within 100 feet of the summit of the hill on the east, and the contact down to the gulch on this side is very irregular and much obscured by débris. There are apparently two or three massive forms of rhyolite here shown, one of them a dark-red porphyritic rock, breaking in sherdy fragments and greatly resembling the decomposed dacite, but distinguishable from it on microscopical examination.

The extension of the tuffaceous area to the southeast, beyond the little divide, is not great, and there are no more massive outcrops. The surface is strewn with granite fragments to the south slope of Bald Mountain, and it is probable that the dikes on the south and southwest slopes of that mountain are connected with the tuff extension, though there is so much wash and soil on this low ground as to hide the connection.

One of these dikes just beyond the map line is noteworthy. It occupies the crest of a narrow ridge, and, while irregular, is not more than 40 feet wide at any point. The greater part of the rhyolite is dense, banded, and more or less plainly spherulitic. In places it becomes a completely spherulitic rock, with several periods of growth, and has afforded very fine material for the study of this interesting structure. The outcrops of massive rock are separated here and there by smooth surfaces, and prospect holes sunk in such places show the typical tuff with a variety of fragments of dense felsitic, spherulitic, or glassy forms of rhyolite. No fragments of granite or gneiss were seen in this place.

From the above facts it seems evident that comparatively narrow fissures served as vents for explosive outbursts, that they were filled by material derived from solid rocks below falling back into them, and that subsequent eruptions of massive material came up through the same channel.

The western slope of Wakefield Hill below the rhyolite is of the Bald Mountain dacite, which is shattered and much decomposed in many places near the contact.

Pennsylvania Hill.—This name is applied to the low rhyolite ridge southwest of Rosita, at the northern base of which the old Pennsylvania smelter once stood. The main mass of the hill is rhyolite, of the same general character as the massive parts of Wakefield Hill. It is in general a dark-reddish, more or less banded rock, showing few porphyritical crystals, and weathering into rough, rounded forms. A distinct spherulitic development was seen in certain places, particularly on the southwestern slopes, and lithophysal structure is also developed locally. The limit of this rhyolite along the southern slope of the hill is a zone of brecciated material consisting partly of rhyolite and partly of the Bald Mountain dacite. It does not seem to be the original contact plane of the rhyolite mass cutting through the dacite, but rather a line of fracture producing an attrition breccia in which fragments of both rocks are mingled.

At the northern base of the hill rhyolite is known to extend down to the valley bottom, at the point where the old smelter was. Excavations here expose a reddish spherulitic rhyolite.

Adjoining the eastern end of the hill is a small space, very much obscured by soil and wash, where the rhyolite dike of Wakefield Hill meets the rhyolite mass of Pennsylvania Hill about on the line between the Bald Mountain dacite and the Rosita andesite. The structure is further complicated by another rock, a mica-dacite, which probably cuts the others in a small, irregular body, not represented upon the map, as its boundaries are unknown. This last rock appears in the bed of Rosita Creek and on the northern bank opposite the eastern end of Pennsylvania Hill. It is probable that the Wakefield fault, and possibly others of small displacement, traverse this ground and add to its complexity.

Area south of Pennsylvania and Wakefield hills.—The district south of these hills is made up chiefly of dacite, cut by rhyolite dikes on the east and overlain by rhyolite flows on the west. Just east of the map line is a double-pointed hill of Bald Mountain dacite, with slopes very similar to those of Bald Mountain. On the west this hill sends out a ridge into the area of the map. The branching rhyolite mass cutting this ridge is of the massive, banded variety seen in Wakefield Hill. The contacts with dacite are frequently marked by a black, brilliant pitchstone, containing but few feldspar crystals and very imperfect spherulites. The transition into banded rhyolite with some lithophysal pores and indistinct spherulitic structure is gradual.

The western arm of the rhyolite, extending down to the little valley, is mainly tuff of the Wakefield Hill variety, and carries a large number of granite and gneiss bowlders. These form a train, which is wide down near the stream bed and narrow up toward the crest of the ridge. Probably they have accumulated on the lower slopes by being washed down from above. Prospect holes show that these fragments come out of the underlying tuff as in other instances which have been described.

In the valley good exposures are rare. Those seen indicate that the dacite is here covered with but a thin sheet of rhyolite, which is largely glassy or spherulitic. The hills to the west are of the generally reddish, banded rhyolite common in this area, and present no features of special interest.

In the limited area of eruptive rocks south of the line of the map rhyolite forms an interrupted line of bluffs, marking the extent of the surface flows to the southward. At the southern base of this line of bluffs is tuffaceous rhyolite, with occasionally some traces of andesitic matter. Through this tuff project knobs of gneiss, and south of Wilmer Creek, which runs westerly along the border of the tuff, one rarely sees any important remnants of material derived from the Rosita Hills.

UPPER ROSITA CREEK, ABOUT THE TOWN OF ROSITA.

The little basin in which the town of Rosita is situated is excavated out of the variable tuffs of the Rosita andesite, and is surrounded by hills of massive dacite, trachyte, and andesite, as shown by the map. Pl. XXXII is from a photograph taken from one of the dacite hills east of the town, looking in a general northwesterly direction. Beyond the town is Pringle Hill, and in the middle background is Mount Robinson, the highest hill of the volcanic group, while on the right is Pocahontas Hill. Of the three most prominent mines of the picture, the one on the right hand is the Virginia, the middle one is the Globe shaft, and that at the base of the Pocahontas Hill is the Humboldt, the largest producer of this vicinity.

The ground underlain by the Rosita tuff is usually smooth and often grassed over, so that the best evidence of the formations here is obtained from mines and prospect workings. These show a purplish breccia or tuff of varying shades, corresponding to the state of decomposition. None of the rock is really fresh.

Massive rock is found in the little ridge between the forks of the creek in the town, and apparently irregular bodies of massive or shattered Rosita andesite may be encountered at almost any point in this formation. Thus, in the Humboldt mine, whose shaft reaches a vertical depth of 700 feet, quite massive-looking andesite was met with at various places in the workings.

The evidence of the Humboldt and other mines shows a considerable depth for the gneissic floor on which the Rosita andesite rests in this vicinity. The northern drifts in the lower part of the mine encountered granite, apparently massive, in the eighth level, and although

VIEW OF ROSITA AND VICINITY, FROM A HILL EAST OF THE TOWN.

Mines indicated by numbers: 1, Virginia; 2, Humboldt; 3, Pocahontas; 4, Leavenworth; 5, Maverick (Senator).

the developments are as yet insufficient to show clearly the nature of this contact, it is probable that the base of the Rosita andesite is less than 1,000 feet below the present surface, except at the vent proper.

The Rosita andesite is cut by a system of trachyte dikes, shown on the map, which cause the little knolls between the Virginia mine and Pringle Hill, as seen in the view shown in Pl. XXXII. These dikes are in all probability the source of the surface trachyte masses of Game Ridge and Plymouth Hill. They are distinctly exposed in many places, and the forking represented by the map is quite characteristic.

Hungry Gulch.—The northern branch of Rosita Creek, locally known as Hungry Gulch, has several forks, one of which heads in the trachyte area to be described in the following section. The other forks are excavated in the Rosita breccia, and have smooth slopes excepting for the irregularities produced by dikes of harder rock. Thus, at the head of Hungry Gulch are several knolls caused by dikes at the ends of little ridges running out from Dutch Flat. One of these dikes, in the ridge nearest Mount Robinson, is caused by a dark, fine-grained andesite with small orthoclase tablets, which has been referred to the Pringle andesite. This rock is shown in some surface outcrops along the ridge and in many prospects. The Indiana and Gray Eagle shafts are among those sunk upon this body. Débris and soil cover the contacts of this dike, so that the outlines given to it upon the map are only approximately correct.

The ridge upon which the Nebraska shaft is situated is traversed by a branching dike of rhyolite breccia, the boundaries of which are not well exposed. It is quite likely that a small and poorly exposed rhyolite dike at the southern base of Mount Robinson near the Humboldt vein is a continuation or offshoot from this dike.

GAME RIDGE–POCAHONTAS HILL.

The trachyte mass.—The large trachyte body which composes the greater part of Game Ridge, Pocahontas Hill, and the adjacent land on the north, is apparently an extrusion, filling a basin whose natural slopes were quite steep. The present boundary lines are chiefly those of primary contact with the Rosita breccia, but several faults have locally determined certain portions of the outline.

The steep eastern and southern slopes of Game Ridge are covered by trachyte débris, and the line with the Rosita breccia is nowhere exposed, though approximately indicated by the elevation at which Rosita andesite becomes mingled with the trachyte. Solid outcrops of trachyte occur at various points not far above the line adopted.

On the south slope of the little knoll between Game Ridge and Pocahontas Hill a surface excavation shows the contact between trachyte above and breccia below to be an uneven plane with a general dip of 23° to the northwest. Here, as in other cases to be mentioned as primary contacts, the border zone of the trachyte exhibits a very fine grain, the crystals are much smaller than in the normal rock, and the transition to coarser and lighter colored rock is gradual, showing the nature of this contact. The Rosita breccia or tuff is hardened immediately adjacent to the trachyte.

Further primary contacts between these rocks are shown in the workings of the Victoria tunnel [29]. This starts in Rosita breccia, runs northwest into Pocahontas Hill, cutting the trachyte at 250 feet from the mouth, and then continues 475 feet farther in solid trachyte. A northeasterly drift which leaves the tunnel at 130 feet from the mouth encounters the trachyte at 110 feet from the tunnel. In each case the contact dips about 15° N.

From above the Victoria tunnel around the southern and western slopes of Pocahontas Hill the contact line is seldom actually seen, though the various openings just below it define its course very closely. In the Caroline tunnel, situated just north of the East Leviathan [20], and but a few feet above Hungry Gulch, and which penetrates Pocahontas Hill in a direction a few degrees north of east, the trachyte contact is cut at about 200 feet from the mouth. This primary contact is quite irregular, but has a general eastern dip of 30°.

At the head of Hungry Gulch the contact is seen up to the Twenty-six fault, which crosses just a few feet south of the Nebraska shaft. By this fault the original contact of trachyte and Rosita breccia is thrown eastward, across the ravine between the Nebraska and the Twenty-six shafts [26]. This fault is particularly described in a succeeding section. From the Twenty-six fault around the hill above the Eureka shaft [27] the trachyte boundary seems to be the primary contact, dipping southeasterly at no great angle. The Eureka shaft and minor prospects lower on the hill slope pass through the trachyte into the Rosita breccia, proving the former to exist as a sheet at this place.

To the eastward of the hill, above the Eureka, the trachyte projects northward in a wedge-shaped mass bounded by fault fissures, in and near which there has been some ore deposited. The vein has been explored in several mines and prospects.

The California fault.—The eastern boundary of the trachyte projection is clearly defined by outcrops, and the character of the contact is revealed in the California, the Horton [22], and the Hard Cash [21] shafts.

In the main shaft of the California claim the contact between the trachyte on the west and the augite-gneiss on the east is found to descend almost vertically for about 20 feet and then to assume a westerly dip of 70°. It had been followed on the dip for 70 feet at the time of visit (1883). The contact is here marked by a streak, or selvage, and some vein matter containing a little galena and barite, and is clearly a slipping plane and not a primary contact.

The Horton shaft follows the fault for 210 feet from the surface (1883), sinking vertically for 100 feet, and then at an angle of about 70°, as in the California. Drifts for 150 feet each side of the shaft prove the strike of the fault to be very nearly north and south. At the Hard Cash a shaft is sunk somewhat more than 100 feet (1883) on the vein, which is said to be vertical for only about 20 feet and then to dip very steeply a little south of west. In all these workings there is selvage or fine attrition material following the contact.

The course of the California fault to the southward is along the eastern slope of Game Ridge, where it is entirely concealed by soil and slide rock, and no prospects seem to have struck it beyond the old California shaft, situated near the crest of the ridge. Not far south of this old shaft a small excavation, just east of the projected line of the fault, reveals reddish, crumbling material, apparently belonging to the Rosita andesite, and still farther south the solid trachyte outcrops on the slopes, likewise east of the projected fault line. These occurrences possibly indicate the appearance of trachyte resting on a remnant of Rosita tuff east of the fault line, although the fact that the influence of the fault on the southern or southeastern boundary of the trachyte mass could not be made out is inconsistent with this idea.

Beyond the Hard Cash mine the California fault is not definitely known. At the old Poorman shaft, near Querida, there is a fault which seems to be very probably the same, but this extension is not proved by the details observable in the intermediate space.

The Nellie fault.—The next most important fault of this area has been shown by developments since the original field work for this report was completed. By a reference to the map it will be seen that the trachyte point is bounded on the west by a line meeting the California fault at a sharp angle. This boundary runs along the eastern base of a low ridge of gneiss and is shown in several shallow excavations, two of which are near the point where the California fault must cross. In these holes the trachyte on the east is found resting on gneiss with an irregular but steep dip to the southeast. There is usually some soft, reddish-brown material a few inches in thickness between the rocks, and the trachyte is much broken and decomposed, so that from these surface exposures alone the character of this contact is not very plain. A short distance to the eastward of the line are two shafts which throw light on the question.

One of these shafts belongs to the Nellie mine [24], and while the data to be given are from hearsay, as the mine has been in the hands of those who would neither give accurate information nor allow of a personal examination, they are borne out by other evidence. The shaft was sunk 120 feet, passing through trachyte into gneiss at about 115 feet, there being some reddish-brown material between the rocks. A level was run 70 feet in a southerly direction on the contact.

The second shaft penetrating the trachyte to the fault plane is the Sleeping Pet [25]. It sinks through solid trachyte and strikes the fault at about 80 feet, where it is an irregular wavy plane with an average dip of scarcely 45° SE. Below this point the dip increases. Here, as in the Nellie mine and at the surface, there is some reddish-brown material on the fault line, which is undoubtedly derived from the layer of Rosita breccia or tuff which occurs under the trachyte and which has been dragged into the fault fissure. The trachyte is much crushed and decomposed near the fault, and there is some mineralization of the crushed fault matter as seen in this shaft.

Still nearer the fault, southwest of the Sleeping Pet, are some shafts, now caved in, which are said to have encountered gneiss under the trachyte at no great depth.

Parallel with the Nellie fault, at a distance of 150 to 180 feet, is a third fault of small displacement. The thin sheet of rock between these faults has been raised a little with relation to the country on the west.

Between these two faults trachyte is seen resting on from 3 to 4 feet of crumbling brownish tuff of the Rosita andesite, the contact dipping south from 15° to 20°, as exposed in a small prospect hole. Within a a few feet of the minor fault, and directly opposite the outcrop of the trachyte contact between the faults, is a shaft (which is indicated but unnumbered upon the map) sunk through about 40 feet of trachyte to the gneiss, showing the amount of displacement of the minor fault. The outcrop of the trachyte contact is thrown more than 100 yards to the northward, where it appears close to a shaft sunk in gneiss, and from this point it runs around the hill above the Eureka, as has been described.

Area between faults.—The data give no evidence as to the thickness of the main trachyte mass between the Nellie and the California faults, and hence there is no means of estimating accurately the amount of displacement of either. West of the Nellie fault the trachyte contact is on the 9,225-foot contour, while it is not certain that trachyte appears at all to the east of the California fault. These facts prove the movement of the latter fault to have been the greater. The amount of displacement on the Nellie fault is estimated at about 500 feet.

The Twenty-six fault.—The Polonia, the Twenty-six, and the Summit shaft of the Nebraska claim are on a fault fissure running nearly east and west. This fault is well exposed in the ravine between the Summit shaft and the main shaft of the Twenty-six [26]. In this ravine the line between trachyte on the south and Rosita andesite on the north is seen to be nearly vertical, and the contact which has been explored by a tunnel on the west side is clearly a fault plane. But this fault is shown by tunnels in andesite about 10 feet from the trachyte wall to be a complex of parallel fissures. The face of the opening on the east side of the ravine shows the rock divided into thin sheets, some of them less than an inch thick. In parts of the complex the rock between the distinct fissures is much shattered and crushed. The main tunnel on the west side of the ravine is also entirely in andesitic breccia, carrying some granitic fragments. In this tunnel a number of bowlders of breccia material were encountered in the vein. They are round, a foot in diameter, very hard, and seem to represent blocks of andesite rounded by attrition during the movement. Similar bowlders of breccia and some of granite were found in the Twenty-six workings. The trachyte fissure contact is also exposed close by the last-mentioned tunnel, and it can be followed up the ridge to the west, crossing it a few feet south of the Summit shaft, which is probably sunk on the fissure complex shown in the ravine below. A short distance down the western slope of this ridge the primary contact with a southeasterly dip meets the fault, which beyond this point is entirely in breccia and can not be traced.

At the main shaft of the Twenty-six the vein is shown to a depth of 130 feet. The mine has not been accessible when visited, but it is said that the 60-foot level is mainly in Rosita breccia, which, if true, would indicate that the shaft is in the northern part of the fissure complex, and at 60 feet has passed through the trachyte thickness north of the main fault into the underlying breccia.

Bowlders of breccia and of granite were taken out of the vein in this mine, as in the tunnel already mentioned.

The eastern shaft of the Twenty-six is sunk 185 feet in trachyte, and the Polonia shaft is said to be 340 feet deep, neither encountering any wall rock but trachyte—facts which show that the primary contact surface of the trachyte and breccia dips quite steeply to the east as well as to the south.

Between the Polonia and Brittle Silver shafts [28] the fault is found to split, the one arm turning southward through the latter shaft, and the other curving slightly to the north. Neither has been followed far from the division.

The southern slope of Pocahontas Hill.—Between the trachyte contact and the Humboldt vein on Pocahontas Hill is a dike of rhyolitic breccia, which is represented on the map. The boundaries are for the most part covered by slide rock, so that the form can not be made out closely, but by means of the data afforded by several prospects the main features of the occurrence are clear. The dike extends from near the East Leviathan shaft [20] nearly to the Victoria tunnel [29], and it seems to be thickest near the center of the known length.

The rock seen at a number of places was once clearly a breccia of a light spherulitic rhyolite, but it is almost wholly decomposed, in the spots chosen for the prospects in it, to a bluish quartzose mass, with angular spaces filled by kaolin and resembling vein matter very strongly. The Transylvania tunnel, on the slope above the Pocahontas shaft, is driven north about 75 feet into this material, nearly at right angles to the dike. Close by the mouth of this tunnel a shaft is sunk in the quartz matter, but by drifting south a few feet the Rosita breccia is found.

Eastward along the dike several small openings show the south wall. One irregular excavation shows trachyte overlapping the upper edge of the dike, as if resting on it. The dike apparently ends near the Victoria, its quartzitic decomposition product being shown in some holes near the tunnel.

DUTCH FLAT.

To the eastward from the northern extension of the Mount Robinson rhyolite dike is a comparatively level area lying between the trachyte mass of Game Ridge and that above Querida. This space is called Dutch Flat, and across it runs the watershed extending eastward from the Rosita Hills.

The flat is diversified by a number of low ridges between shallow drains, and the surface is to a large degree covered by alluvium, so that outcrops are rare. The prospect shafts which are distributed over the surface often penetrate to rock in place, however, and show that the Rosita andesite underlies the entire area, chiefly in the form of loose tuffaceous material and more rarely in the form of breccia or massive rock. The eastern limit of the andesite is a shallow drain, beyond which only gneiss appears. It is quite possible that a small fault runs down this boundary drain, parallel to the Nellie fault.

From the Mount Robinson rhyolite dike, which forms a little bench of outcropping rock, eastward to the Querida road, the surface wash is quite deep, excepting where the dike of hard Pringle andesite appears. In the wash are many earthy rhyolite fragments, and some of the shafts show a mixture of soft, reddish andesite with nearly white matter which resembles rhyolitic mud. A small outcrop of rhyolite on the little ridge north of the Quaker City, and the frequent appearance of the white material in the wash, make it seem probable that a sheet of fragmental rhyolite once covered these flats at about the present horizon.

Below the Querida road as far as the line of granite and gneiss the much decomposed and crumbling Rosita tuff is shown by many prospects. This often contains granitic fragments, and the latter formation doubtless underlies the tuff at no great depth. A few abandoned shafts near the border seem to have penetrated the gneiss, but this could not be proved.

MOUNT ROBINSON.

Directly west of Dutch Flat rises the highest hill of the group. It presents unusual topographic features, in that its summit is a rough, projecting ridge with an abrupt southern face, sometimes forming jagged cliffs, while on the north an aspen-covered slope rises nearly to its top. This rugged crest is shown in Pl. XXXII. Westward from the summit a shoulder overlooks the basin at the head of Leavenworth Gulch and is connected with the Robinson Plateau by a high divide.

These features are wholly due to the characters of the rocks making up the mountain. The rough crest is caused by the hard quartz-alunite rock, the decomposition product of a broad rhyolite dike, which was fully described in the preceding chapter. The slopes east and south are of the soft Rosita andesite. The western shoulder is mainly due to a dike of Fairview diorite, which is much less decomposed than either the Bunker andesite or the Rosita breccia, rocks which meet on this slope along a line not accurately determinable in detail.

The eastern and southern slopes.—There is much débris and slide rock on the slope of Mount Robinson toward Rosita, and, as the underlying andesite is as a rule much decomposed, it would be difficult to obtain satisfactory data as to the structure were it not for the mines and prospects, which are quite extensive in some places. The Humboldt-Leavenworth vein runs in a nearly straight line along the base of the mountain, and, although comparatively barren in this portion of its course, it is very sharply defined by numerous prospect holes. The rock shown in these excavations and in outcrops near by is plainly the typical Rosita andesite, often in nearly massive form, though more commonly brecciated. The transition from the massive rock to the breccia is seen here very clearly, the solid rock being locally traversed by thin reddish seams marking fissures, upon which there has been, in some places, no visible dislocation, while in others the extent of the displacement can be readily seen.

Between the Humboldt vein and the altered rhyolite dike of the summit the Rosita breccia is the dominant rock, a careful examination of the much bleached material shown in numerous places failing to identify any other rock of similar character. Low down on the southern slope there seems to be a dike of earthy rhyolitic breccia, which is probably an offshoot from the dike in the knolls at the head of Hungry Gulch, though a surface connection could not be established.

The Seneca tunnel, situated on the eastern slope of the mountain, below the dike, is driven 600 feet N., 37° 40′ W. At 507 feet it cuts the quartzose material of the rhyolite dike, and then continues 93 feet farther without noteworthy change in the rock encountered. The Rosita breccia passed through was for the most part bleached and soft, but some of it was brown in color and of distinct structure. Several small irregular quartz veins were cut in the bleached part of the rock, and at 470 feet a trachyte dike 12 feet wide was encountered, the rock being much decomposed. This dike was not identified upon the surface. Some of the material from the large dike shows the rhyolitic structure, but most of it is far gone in decomposition.

Other tunnels and shafts below the rhyolite dike, near the Seneca, exhibit the much decomposed condition of the Rosita breccia in this vicinity. An examination of the dump of the Seneca did not show any alunite-bearing rock.

The workings of the Matchless and Leavenworth mines, on the southwestern slope, show Rosita breccia in its most typical form as the wall rock. West of these mines almost the whole mass of rock on the slopes of Mount Robinson is so thoroughly decomposed that it becomes impossible to determine where the Rosita andesite ends and the Bunker andesite begins, while it seems certain that rhyolite cuts both in dikes now represented by certain quartzose veins.

The most prominent of these masses of supposed altered rhyolite is in the ridge next west of the Matchless mine. It forms an almost continuous outcrop from near the point where the Mount Robinson dike seems to terminate down to a knoll near the Matchless shaft. The mass is in some places dense, in others porous, and gives no indication as to the structure of the rock from which it came excepting in two small prospects midway on the slope, where suggestions of spherulitic structure may be seen. No sharp contacts of quartzose rock with the adjoining andesite were exposed, and especially on the west side of the ridge the country rock is also much decomposed, a part of it being silicified so as to resemble the other. The proximity to the great dike of the summit makes it seem likely that an offshoot from it runs down this ridge and has been decomposed, as has the larger mass.

Rosita andesite appears in the forks of Leavenworth Gulch, at the base of Concord Hill, in a little knoll of dark-red massive rock, which is almost the only place where unbleached rock of this type can be found north of Leavenworth Gulch.

From Mount Robinson toward Concord Hill the country rock is white, and is either muscovitized or silicified to a degree preventing a recognition of the characteristics distinguishing the Bunker from the Rosita andesite. The line dividing these two types as drawn on the map is approximate only. To the west of that line the rock presents a more uniform grain and less brecciated matter than is found in areas belonging to the Rosita rock.

The western shoulder of the mountain.—The spur of the mountain projecting westward presents a small irregular mass of Fairview diorite, a part of which, as at the Sunset shaft, is rather coarse-grained and thus easily recognizable, but passes toward its contacts into fine-grained porphyritic rock very much like the Bunker andesite in appearance.

The interior and coarser part of the body is fresh, while near the border it is decomposed, increasing the difficulty in distinguishing the rocks and in defining their boundaries. As the Bunker rock is surely the predominant one and the other merely an irregular dike, the difficulty is not of much geological significance. It affects only the determination of form of the less important body. The beginning of the steep slopes of this spur west and south marks the change of the more completely altered Bunker andesite.

The rhyolite dike.—The rough crest of the summit ridge of Mount Robinson is made of bluish or gray, predominantly quartzose material, cavernous or porous in some places and compact in others. Alunite and diaspore are the only other minerals associated with the quartz of this rock. It is certain that this alteration of the original rhyolite has been accomplished by solfataric exhalations. Following the crest of the ridge from the summit northeasterly to Dutch Flat, one finds scarcely a trace of the original rock structure remaining. But at the Sedgwick shaft, where the dike merges into the slope of the flat, the rhyolitic character is plain.

The original character of the great dike is also shown on the contact with the Rosita breccia at the base of the cliffs, about opposite the summit. Here several shallow prospect holes have explored the contact and revealed spherulitic and brecciated rhyolite, only partially changed to the quartzose matter. An interspherulitic glass was once present. The southeastern wall of this dike is actually known only in a few places—at the prospect above noted, in the Seneca tunnel, and down near the junction with Dutch Flat. These all serve to show that the contact runs near the base of the cliff presented on this side. The opposite or northwestern wall is not known in any place, the contact on this side being concealed by soil and débris which no prospect hole has pierced, excepting down on the low ground between the flats and Robinson Plateau. The width of the dike on the mountain proper is thus largely a matter of conjecture. It is presumably somewhat greater than the crest of altered rock. The southern line is nearly correct as drawn; the northern may possibly be situated farther down the slope, under the wash, but it can not be placed much nearer the crest than it has been.

The western end of the dike is upon the southern slope of the western spur of the mountain. It is plain that the dike narrows rapidly westward from the summit, and it can not be traced beyond the limit shown by the map. Débris covers the slope about the ending, and it is thus not plain whether a direct connection exists between the western end of the main dike and that running down the ridge west of the Matchless, but such a forking would be eminently natural.

This much-metamorphosed rhyolite dike is plainly one of the channels through which the material of the surface rhyolite flows ascended. It is to be compared directly with the channel of Democrat Hill and the dike of Knickerbocker Hill. All three are much decomposed, with similar products. While barite is locally found in large masses in the quartz material, ore minerals seem to be very rare in this great quartz vein. No ore body, nor any indication of great promise, has been found, so far as the writer is aware, in any of the prospects.

The northern slope.—As intimated in the preceding section, there are no outcrops on the northern slope of Mount Robinson from the rhyolite ridge down to the shallow drain which marks the line of the Robinson Plateau. The slope is almost entirely covered by a dense growth of aspen and evergreens. Beyond the drain the rock is much decomposed, but seems to belong to the Bunker andesite. As the Rosita breccia is cut by the rhyolite on the south side, it is reasonable to assign to the same rock a certain development on the north, and it is probable that the greater part of the covered area is underlain by the Rosita andesite.

THE QUERIDA TRACHYTE AREA.

Between Bassick Hill and Dutch Flat is an area occupied mainly by trachyte, which is for the most part a surface flow, while the presence of dikes below it seems to be demonstrated in certain places. In different parts of its present border this trachyte comes in contact with gneiss, Rosita andesite, Bunker andesite, Bassick andesite agglomerate, and rhyolite. These rocks are in many places much decomposed, and surface materials conceal many of the most important contacts. The structure is also complicated by faults, clearly shown in some places and roughly indicated in others.

Altogether, it must be said that available data do not lead to a thorough understanding of the complex structure of this area, although the surface distribution of the trachyte is substantially correct as represented on the map.

The western division.—West of the road between Querida and Rosita the trachyte forms two ridges descending toward Bassick Hill. They are smooth and the rock is usually much decomposed. The boundary with the bleached Bunker andesite is apparently along a small gulch, as indicated, but the contact is obscure and the rocks in their decomposed state are not easily distinguished from each other. About in line with the western contact a narrow dike of trachyte cuts the Bunker andesite of the plateau, extending toward the summit of Mount Robinson. The main contact turns east at the north end of this dike and is clearly exposed in the ravine which runs directly toward Querida. Between this ravine and the road to Rosita is a small but very complicated area, the geology of which is obscured by the surface deposits, by the decomposed condition of the various rocks concerned, and by more or less faulting. The presence of several faults in the banks of this ravine where it curves about the prominent point shown on the map is indicated by the fissure contacts between different rocks shown in various tunnels and shafts, but it was not possible to determine the effects of these faults accurately in the short time which could be given to this spot. The structure as represented by the map is much simpler than it is in reality.

East of the Julianna mine the trachyte boundary is soon reached, and, though the nature of the contacts is seldom well shown, the surface features would seem to indicate that the line is due to the erosion of a sheet resting on andesitic breccia or rhyolite. The only place where the actual line of trachyte of this vicinity was seen is south of the Julianna, where, on the south side of the ridge, a contact between trachyte and Rosita breccia is shown in some trenches as an irregular primary contact plane dipping northerly about 45°.

The Querida trachyte is a porphyritic rock with much smaller sanidines than are seen in the Game Ridge trachyte, and the grain is like that of the larger dikes. From the occurrence of two large surface bodies so near each other, however, it seems probable that, whether from the same source or not, their lavas may have joined at some point.

The eastern division.—The area southeast of Querida is mainly occupied by trachyte. Numerous prospect holes pass through the prevalent surface wash into the solid rock and prove the presence of a considerable mass of trachyte, while few of them are deep enough to be of service in determining the relations between the trachyte and the underlying rock. The road leading from Querida up the drain to the south is exclusively in trachyte débris as far as the divide. East of this road to the Poorman mine the trachyte is apparently a thick surface flow. At the old shaft of this mine, located west of the one to which the name on the map is attached, the workings prove the presence of a fault explaining the gneiss outcrop adjoining on the east. (See also map of Pl. XXXIII.) The old shaft is sunk 120 feet upon a fault contact between trachyte and gneiss, which has a strike of N. 40° W. and a dip 70° to 80° SW., with trachyte as the hanging wall. A drift runs 112 feet southeast on this fault line, which is characterized by some selvage and quartzose vein matter impregnated with galena and zinc blende. The course of this fault and the downthrow on the west indicate that it is the continuation of the California fault, seen in Game Ridge.

The fault is not so distinctly shown elsewhere in the trachyte area, and it would seem that if the trachyte sheet had ever extended to the southward it would now appear on Dutch Flat west of the projected fault line. That it does not do so, and that in spite of the Poorman fault the southern limit of the trachyte sheet is a straight line, may be good ground for suspecting the existence of a fault running from the disturbed area referred to in the preceding section along the southern boundary of the trachyte.

The new Poorman shaft is sunk on a small outcrop of gneiss, which it penetrates for 195 feet, encountering no other rock. The gneiss outcrop is small and is surrounded by trachyte, as shown by outcrops and numerous shallow prospect holes. A little southeast of the new shaft a prospect passes through trachyte into Rosita andesite at about 60 feet, and, according to Mr. Eakins, another shaft penetrates gneiss under the trachyte, judging from the rock on the dump. The shaft was inaccessible. These facts and others to be cited show that the thickness of the Rosita andesite covering the surface prior to the trachyte eruption was very variable.

From the Poorman shaft eastward to Cottonwood Gulch the surface geology corresponds with the requirements of the idea of a thin trachyte sheet resting upon an uneven surface of gneiss or of Rosita tuff and breccia, locally covering the gneiss. The trachyte runs out to the eastward on all small ridges, while prospect holes in several places show the presence of Rosita andesite below, and the same is exposed in the drains which cut through the trachyte. But the workings of the Julianna and Bullion claims [13] show such relationships for the rock masses that one must assume the presence of dikes and probably of small faults in that vicinity. At the surface between the two shafts in question is an outcrop of gneiss in which a prospect hole has been sunk for a few feet. All about it is Rosita tuff and andesite, but the Julianna, close by, sinks 150 feet in the same material.

In contrast to the facts just presented are those shown in the Mayde shaft [20], situated only about 200 feet away from the gneiss outcrop. This shaft is sunk with an easterly dip of 60° or 70° to a depth of 485 feet. The lower 25 feet was in gneiss; the rest is all in trachyte. At 150 feet in depth a level runs north 90 feet, all in trachyte; and another very irregular one runs southward 60 feet in trachyte. From the latter a western branch penetrates Rosita breccia, but on turning slightly northward it again encounters trachyte and continues in the same for 140 feet. The direction of this drift will carry it somewhat north of the gneiss outcrop which has been mentioned. At 300 feet short drifts were run from the shaft, all in trachyte.

Comparing these facts with those of the surface outcrops which have been mentioned and are represented on the map, it seems evident that there must be a considerable dike mass of trachyte at this place. Unfortunately no evidence could be obtained as to the character of the contact between the trachyte and the granite at the bottom of the Bullion shaft. It is assumed that it was the contact of a dike cutting the gneiss.

Northward from the Julianna mine the slope toward the Bassick Hill is mostly covered by soil and wash, penetrated by a few deep prospect holes. All the evidence points to the presence of a brownish-gray tuff material, and this has very decidedly the characteristics of the Rosita andesite, although it is very much decomposed, and, as will be shown, the Rosita andesite formation must come in this vicinity in contact with the fragmentary products of the Bassick eruption. The facts concerning the distribution of the Bassick rock will be given later in describing the Bassick eruptive channel.

MOUNT TYNDALL-BASSICK HILL.

The area to be described under this head is a small one at the northeastern extremity of the Rosita Hills. It is unique in character, for the main surface rock is a true agglomerate of andesitic material, and beneath a part of it is the volcanic channel through which the eruption took place. In this neck is the celebrated Bassick mine. In order to illustrate more clearly the structure of this important and interesting area, the map of the surface occupied by the Bassick agglomerate has been enlarged and is presented on Pl. XXXIII, with profile sections on Pl. XXXIV.

The surface geology.—Mount Tyndall, the highest point of the area, is one of the most regular cones of the region as regards its upper slopes, as may be seen from the view presented in Pl. XXXV The mountain has a capping of dense banded rhyolite, which breaks up by weathering into rather small angular blocks. Slide rock of such fragments conceals contacts with softer agglomerate on the south and east, and also with the gneiss on the north. A scanty soil supports some short grass, and a few stunted evergreens appear near the summit. The exposures at the western base of the mountain and on the northern slopes show that this rhyolite mass belongs to a flow, which, along these borders, rests either upon gneiss or upon a thin and variable remnant of the Rosita andesite tuff.

The eastern and southern slopes of Mount Tyndall below the rhyolite, the entire mass of Bassick Hill, and the short ridge to the eastward on the west bank of Tyndall Gulch are made up of an agglomerate that is bounded on the east by the gneiss along the line of Tyndall Gulch, and on the west by Querida Gulch. On the south the surface limits of the agglomerate are less distinct, for it there meets the soft and crumbling Rosita tuff in the low ground east of Querida. The map of Pl. XXXIII gives the entire surface extent of the Bassick agglomerate and shows its relations to all other rocks.

Pl. XXXV is a view from a photograph taken from the trachyte ridge south of Querida, looking almost due north over Bassick Hill to Mount Tyndall, the profile of Mount Tyndall there seen being that of section *cc*, Pl. XXXIV. It gives a good idea of the smooth, débris-covered slopes of Mount Tyndall, and shows the pitted surface of Bassick Hill. Near the top of the hill is the great new shaft house. Below are the shops at the tunnel entrance and the mill. In the bed of the gulch below the latter are the slime ponds.

Owing to the loose texture of this fragmental rock, prominent outcrops are usually wanting. The rhyolite capping of Mount Tyndall has, however, protected the formation there, and in Bassick Hill the matrix of parts of the agglomerate has been silicified or otherwise hardened so that these portions stand out in contrast to the less altered parts.

At various places on Bassick Hill the character of the agglomerate can be well seen in the natural outcrops, and excavations have further exposed the rock. On the western slope above the mill is a projecting outcrop, and rock has been quarried from this for the foundations of the new shaft house. In excavating for the latter good exposures of the agglomerate have also been made. In both places the rock is most clearly fragmental, the size and form of the fragments varying throughout, some of them being rounded pebbles or bowlders, while others are subangular, and few if any are sharply angular. In size they range from gravel stones to blocks 3 feet in diameter. In these exposures the matrix is white and often homogeneous in appearance, being in certain parts hard and flinty, in others earthy and crumbling—differences due to the fact that in the course of decomposition the residual products, silica and kaolin, have been locally concentrated.

On the southern slope of Bassick Hill a small outcrop exhibits many very evenly rounded pebbles, forming a conglomerate. On the top of the hill the great variability in size and shape of fragments and in alteration products is very clearly shown.

The agglomerate of the ridge between Bassick Hill and Mount Tyndall consists of subangular blocks of andesite, many of them several feet in diameter, embedded in a fine, gravel-like matrix. The rock fragments are nearly all of the same general type—an augite-biotite-andesite of holocrystalline groundmass—and although they are less decomposed than the smaller fragments of Bassick Hill, they are still much altered, and their surfaces are usually much more stained by brown iron oxide. In the upper part of the ridge large fragments abound, and so many have weathered out and fallen down the slope that they seem at first to come from an outcrop of solid rock. . In reality the lower slopes of this connecting ridge are made up of fine-grained material, corresponding roughly to the matrix of the upper part.

In the upper knoll on this ridge is a very small, irregular dike of a dense black rock, which can be traced for only a few yards down the eastern slope, where it is lost under the débris. It is 3 or 4 feet wide in places, with irregular walls, owing to the soft material which it cuts. It has been described in Chapter II as a limburgite, and is remarkable for its almost fresh olivine crystals, the only porphyritical constituent. The fresh condition of this dike is one of the significant facts bearing upon the question as to the time at which the general decomposition and ore deposition of the region took place.

Near the rhyolite on the south face of Mount Tyndall the agglomerate appears as a rather firm, reddish-brown breccia, in which the matrix is stained and hardened by deposition of hydrous iron oxide. A prospect hole is sunk in this breccia near the rhyolite (*l* of map, Pl. XXXIII). Some of the fragments here are 2 or 3 feet in diameter.

The slopes east and west of this connecting ridge show prevailingly fine-grained material, like gravel or ash, but in this are here and there larger blocks of andesite. Tunnels in this fine-grained substance will be referred to in a later paragraph. As far as can be seen, the material under the rhyolite débris on the southern and eastern slopes of Mount Tyndall is like that of the ridge to the south. Toward the base of the eastern slope there are numerous outcrops confirming this.

The character of the agglomerate near the gneiss on the northeastern slope of Mount Tyndall is quite plain. It is not so thoroughly or uniformly decomposed as near Bassick Hill, and parts are decidedly purplish or brown in color, thus causing a superficial resemblance to the Rosita tuff and breccia. While prevailingly of small fragments lying in gravel or ash, there are some masses which seem at first like outcrops of intrusive dikes. Among the rock fragments the purplish Rosita andesite may be most positively identified both as tuff and breccia. Probably the finer dust and sand of the same rock causes the general color tone of parts of the agglomerate.

Down near Tyndall Gulch and near the gneiss there is a very plain stratification to the materials of the agglomerate, the only place where this arrangement is markedly developed as far as observed. The dip is slight to the southward. Gneiss is present through all the agglomerate near the contact, but does not seem any more abundant there than in other parts farther removed from the boundary.

Up near the rhyolite, on the northeastern shoulder of Mount Tyndall, is a long tunnel (*m*) which was directed, under the guidance of a spiritualistic medium, toward the center of the mountain. It did not reach the predicted bonanza, but it serves to show that underneath the rhyolite at this point is a fine-grained, light-gray tuffaceous matter like that from the Centennial tunnel, which will soon be described. It is well stratified, with a northeasterly dip of a few degrees. This material is traversed by the tunnel for about 100 feet, and then it meets a reddish-brown and plainly andesitic stratum. Somewhere beyond that point it encounters the rhyolite, a portion of it being glassy and some earthy, with inclusions of andesite. The relations of these rocks could not be ascertained, as the tunnel had caved in at time of visit. The glassy rock probably comes from a contact zone, however, and may indicate that the dike or conduit through which the rhyolite came up has been cut into.

The upper part of the ridge on the western bank of Tyndall Gulch is made up of breccia, which is dark reddish-brown and resembles that near the rhyolite on Mount Tyndall in its state of preservation. It is considered as a part of the agglomerate resting upon the Rosita breccia.

No sharp line between the Bassick agglomerate and the Rosita breccia is shown upon the ground. The Rosita tuff is known to underlie the trachyte about the Poorman and Julianna mines, and to extend down the northern slope into the depression southeast of Bassick Hill. All the shafts on this slope which reach rock in place under the deep soil show a fine, soft, mud-like tuff of purplish or lilac colors, unlike anything in the agglomerate, but typical of the Rosita rock. Even the Lizzie Mac (*r*) shaft, directly east of Bassick Hill, shows predominant purplish andesitic matter, more plausibly referable to the Rosita andesite than to the agglomerate; and the shafts near the Hector and Mountain Boy mines seem to be in bleached andesitic breccia of the Rosita type. Only underground work, such as drifts from the Bassick shaft, can settle the limitations of the agglomerate to the southward.

The Bassick and P & O mines.—The deep workings of these two mines under Bassick Hill give most important evidence concerning the character and the position occupied by the agglomerate formation. Without this evidence one would scarcely be justified in assuming the origin for this material which it now seems necessary to suppose. Yet the only new information concerning the agglomerate which is supplied by the mines is the proof of its distribution in depth. In character, the material passed through does not exhibit any variations not seen upon the surface of Bassick Hill.

In his paper upon the Bassick mine, Grabill[1] represents the rock fragments surrounded by ore to be very generally round in shape and of rather small size. From the testimony of Dr. G. C. Munson,[2] a former superintendent of the mine, and from personal observation, it seems to the writer more probable that many of the fragments spoken of as rounded were subangular, and that there has been also a much greater variation in size than was specified by Grabill. In some of the stopes between the seventh and eighth levels the writer noticed a number of irregular fragments, each several feet in diameter, and in a lower level of the mine the same variations in shape, size, and nature of the fragments may be observed as on the surface of the hill. The ore-bearing mass from the twelfth level, 1,400 feet below the top of the hill, can hardly be distinguished from that of the quarry above the mill in regard to the rock fragments it contains.

Gneiss and granite fragments occur in the agglomerate throughout the mine. On the eighth level some large pieces of granite and others of mica-gneiss were found. Near the bottom of the present working there has been less of these rocks encountered than at various higher horizons. Among the rocks occurring in large fragments at the eighth level are some of an eruptive breccia, undoubtedly the Rosita breccia.

In the P & O claim, on the north side of Bassick Hill, the agglomerate has been explored to a depth of 750 feet and several hundred feet of drifting has been done. So far as known, the agglomerate encountered did not present any variations not seen in the surface rock. At the end of the 700-foot level, which runs north, gneiss and granite fragments were found in great abundance, but no boundary to the formation was discovered. Changes from fine agglomerate to coarser, breccia-like material were found in places, but no sharp lines exist between them. In 1888 the entire outer part of the dump of this prospect had become so fully disintegrated as to be merely a mud containing a few fragments of solid rock.

Data of tunnels.—Two long tunnels penetrate the fine-grained agglomerate of the ridge between Bassick Hill and Mount Tyndall. Their positions are shown in Pl. XXXIII.

The Centennial tunnel starts from a point on the western slope of the ridge and extends 350 feet in a northeast direction. It begins in an ash-like material with some appearance of horizontal bedding. The microscope shows the particles of this ash to be so far decomposed that one can not definitely say that they were not originally of glassy character.

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[1] On the peculiar features of the Bassick mine, by L. R. Grabill: Trans. Am. Inst. Min. Eng., Vol. XI, 1883, p. 110.

[2] Personal communication to the writer.

A. Hoen & Co. Lith. Baltimore.

GEOLOGICAL MAP OF BASSICK HILL AND VICINITY, COLO.

ENLARGED FROM GENERAL MAP PLATE XXVI.

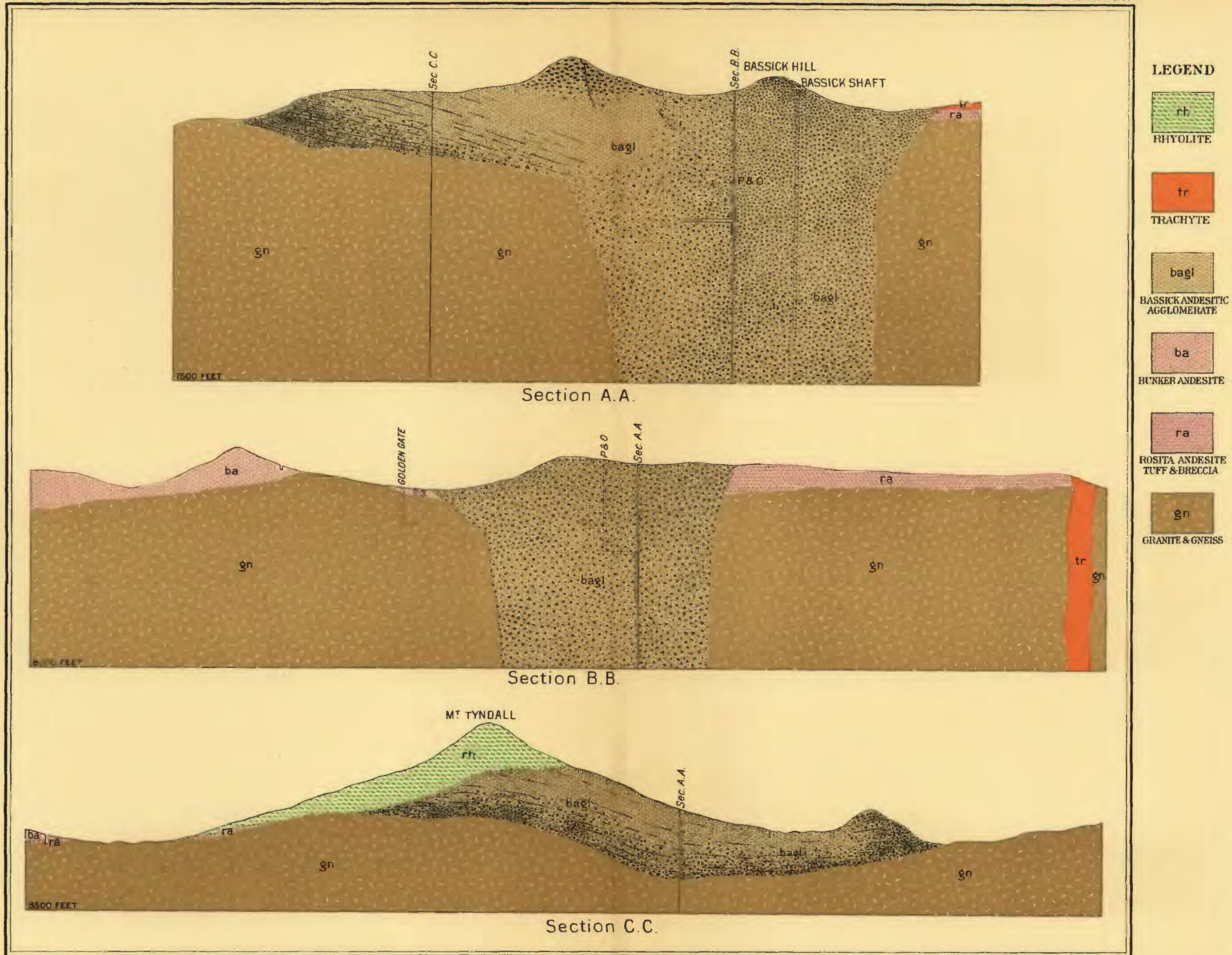
BY WHITMAN CROSS.

1896.

Scale: 1 inch = 600 feet.

600 500 400 300 200 100 0 600 1200 1800 ft

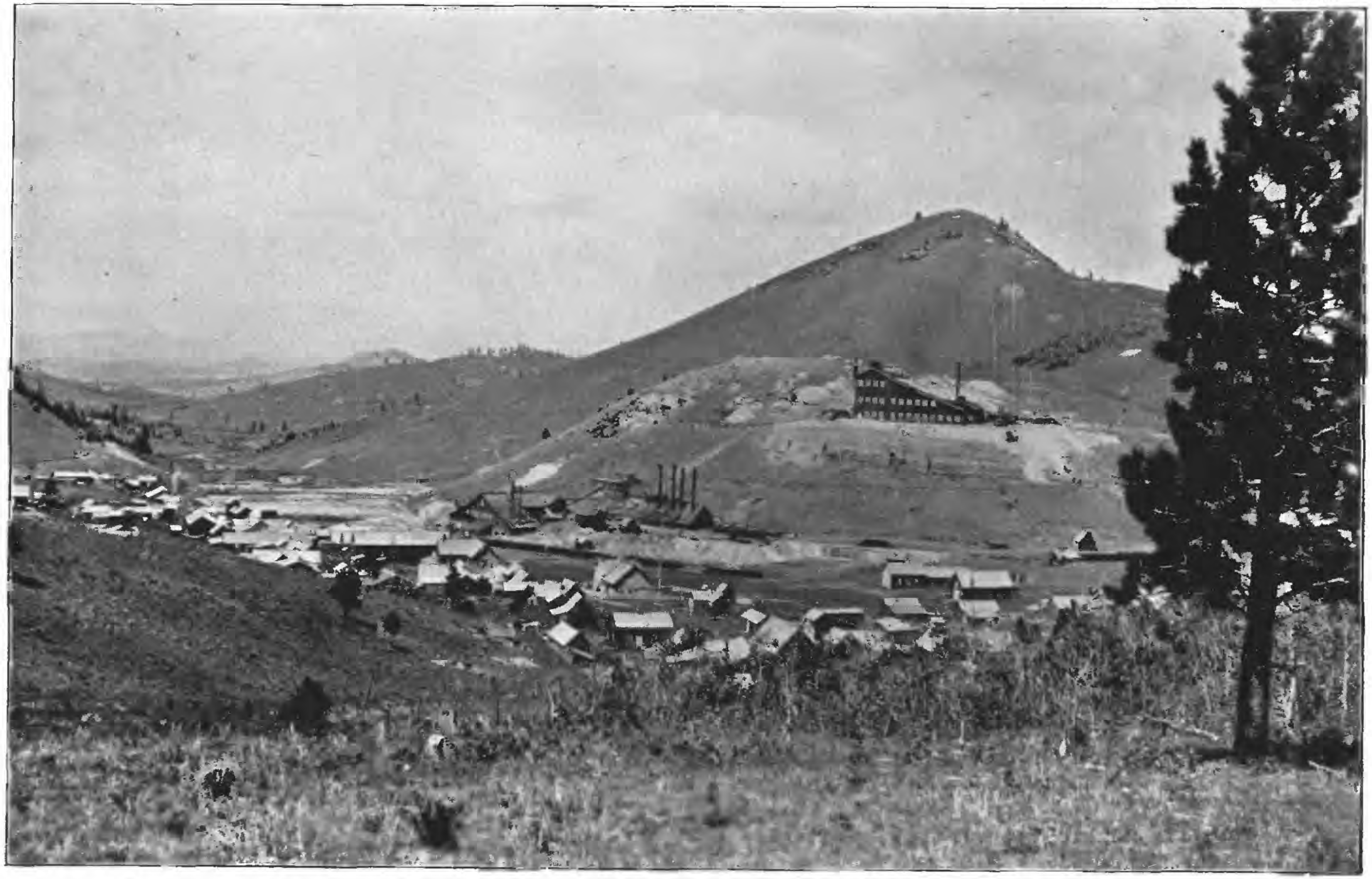
Contour interval 25 feet.



GEOLOGICAL SECTIONS THROUGH BASSICK HILL AND VICINITY, COLO.

Scale

600 500 400 300 200 100 0 600 1200 1800 FT.



VIEW OF BASSICK HILL AND MOUNT TYNDALL, FROM THE SOUTH.

From the western base of the ridge a tunnel (*p*) runs 750 feet west. In this length almost all the material passed through was fine-grained, as in the Centennial. It is made up largely of gravel stones less than 0.5 cm. in diameter, embedded in a dust of varying quantity, and as it is thoroughly bleached and decomposed little evidence of its original character can be made out. There are some fragments of apparent Rosita breccia embedded in this tuffaceous material.

The profile sections.—As stated in Chapter II, the Bassick agglomerate is conceived by the writer to occupy a true volcanic channel. The part now seen is thought to be a remnant of the mountain of fragmental materials ejected from the vent below, and barely conceals the line of intersection between the orifice proper and the original surface.

To clearly express the known data as to the distribution of the agglomerate and its relation to the other formations, and to illustrate the above idea as to its nature, three profile sections have been constructed, whose courses are shown on Pl. XXXIII, and they are assembled in Pl. XXXIV.

In these sections the boundaries assigned to the agglomerate are, of course, entirely hypothetical, but the data afforded by the gneissic boundaries of the surface and by the Bassick mine workings in depth are alone sufficient to compel the assumption of very steep limits for the agglomerate in certain places. The lines drawn in the profiles illustrate the conception that there is a channel of approximately vertical walls and general oval section which near the surface naturally enlarges to a funnel shape. For the representation of the sections a certain position was necessarily assumed for the vertical channel. All the known information bearing upon this question will be given in discussing individual sections.

Section AA.—This section, which runs in a northeasterly direction through Bassick Hill and across the eastern slope of Mount Tyndall, expresses the idea entertained as to the underground structure of the Bassick agglomerate mass. The principal facts of the line of section are furnished by the Bassick shaft adjoining the section, the P & O workings, the long tunnel (*p*), and the stratified materials of the ridge east of Mount Tyndall. It is assumed that the longer diameter of the supposed oval vent lies near the line of section.

The character of the agglomerate in different parts of the mass has been rudely indicated in the sections. The Bassick workings show a nearly uniform, chaotic mixture of subangular or rounded bowlders, with gravelly matrix, and similar material is met with in the P & O, though probably somewhat finer grained in some parts. The long tunnel (*p*) encounters only fine-grained tuff, while in the hill above it large blocks are held in the tuff.

In the ridge cut by the section occurs the small dike of limburgite, which is represented in solid black. This doubtless continues in depth, but not necessarily in the line of section. A conduit for the rhyolite of Mount Tyndall probably cuts the agglomerate, but presumably not on this section line.

Section BB.—This is situated nearly at right angles to the preceding, and passes through the workings of the P & O claim. The definite facts along this line are (1) the gneissic outcrop of Tyndall and Querida gulches, (2) the developments of the P & O, (3) the trachyte dike at the Hector mine, (4) the Bunker andesite of the western hills, and (5) the data of the Golden Gate shaft, near the section line.

The Golden Gate shaft is 200 feet deep, the upper part being in a broken mass of Bunker andesite. Below this is gneiss, also much shattered, and from the bottom of the shaft a drift runs 50 feet nearly east in gneiss. The close proximity of the gneiss to the shafts of the P & O and Bassick mines necessitates the assumption of a very steep descent for the western wall of the supposed channel on the line of this section. And if the Lizzie Mac shaft (*r*) is in Rosita tuff, as the material of the dump would indicate, the eastern wall must be very abrupt also. The section represents the diameter of the neck at the level of the drift in the P & O as about 1,200 feet. The Hector shaft, sunk nearly on the contact with the trachyte dike, has evidently passed into gneiss west of the dike, or else drifts across to it; but from the fact that holes situated between the Hector and the Mountain Boy penetrate gneiss under the Rosita tuff, the former explanation of this rock on the Hector dump seems justifiable. As in many other cases of this region, these mine workings were inaccessible at the time of the visit.

Section CC.—This section runs nearly east and west through the summit of Mount Tyndall. The important facts of this section are (1) the gneiss and granite exposures of Tyndall and Querida gulches, and (2) the layer of purplish Rosita andesite tuff between the rhyolite and gneiss on the one side of Querida Gulch and between Bunker andesite and gneiss on the other side.

To the westward of the region included in the map (Pl. XXXIII) the purplish tuff passes into breccia, and is found in varying development between gneiss and the Bunker andesite or the rhyolite. It occupies the place of and is identical with the Rosita andesite, as far as can be determined, and fragments of the same material occur in the Bassick agglomerate.

In Section CC the layer of Rosita tuff is shown as a remnant. The rhyolite sheet probably has the general thickness assumed, but its relations to the Bassick agglomerate and the extent of the latter formation in the mass of Mount Tyndall are not clearly shown; from the data of the tunnel (*m*) on the northern slope, given above, however, it seems clear that the rhyolite rests on the agglomerate.

The line of section runs north of the assumed boundary of the vertical channel, and therefore the agglomerate appears as if occupying a basin-like depression in gneiss. (See Section AA.)

ROBINSON PLATEAU.

The Robinson Plateau is the elevated area northwest of Mount Robinson, and lies in about the center of the tract occupied by the Bunker andesite. Toward the west it is narrow and ends in two conical points.

The northern and southern edges are rather abrupt, except for ridges which connect the plateau with outlying points. Eastward the slope is gradual toward Dutch Flat, and this slope would doubtless have been extended southeasterly had not the hard quartzose decomposition product of the rhyolite dike afforded so strong a resistance to erosion as to cause the high ridge of Mount Robinson.

The northern edge of the plateau.—From the Ben Franklin mine westward to the Racer there are many outcrops of comparatively fresh rock in the projecting points and in the ravines between them. The prevailing rock is the Bunker andesite, with a dike of the Fairview augite-diorite running parallel to and just back of the plateau edge. When the diorite is coarse-grained and fresh, as near the Racer, Michigan, and Dinero claims, the rock is easily distinguished by its large brown mica leaves and granular structure from the denser Bunker andesite, but as the eastward ending of the dike and its contact zones are fine-grained and somewhat porphyritic, it is practically impossible to fix the boundaries where the two types are bleached out or imperfectly exposed.

Immediately below the edge of the plateau on the north the steep slope is for the most part covered by a growth of aspens, low pines, and underbrush. The few prospects there found show, as a rule, very much decomposed rock of Bunker andesite.

The western point of the plateau, where the Racer claim is located, is cut by the augite-diorite dike, which is lost under débris and soil on the western slope. The andesite and much of the diorite is bleached from numerous fissures outward. On the southwestern slope, near the top, is a zone of light brecciated rock, which on microscopical examination proves to be peculiar, and is probably a thin dike of material belonging to some one of the later andesites found on outlying ridges of the hills. The groundmass shows a distinct flow structure, and large zircons are characteristic of the rock.

The southern edge of the plateau.—Between the Racer point and Mount Robinson the edge of the plateau is broken by two prominent projecting points of moderately fresh Bunker andesite, while the steep slopes toward the branches of Leavenworth Gulch are of white and often extremely decomposed rock, which prevails for some distance in this direction.

The rock of the two points is a rather coarse-grained modification of the Bunker andesite, which bears a strong resemblance to certain facies of the Fairview diorite, but the transition to the adjacent Bunker type is clear enough to determine the relationship in this case.

The plateau proper.—The gradually sloping surface of the plateau presents few marked outcrops, being covered by soil or slide rock. The rock of the outcrops and that shown in prospect holes is usually bleached, but still hard, and can be identified as belonging to the Bunker andesite. In a number of places, particularly at the western end of the plateau, prospect holes have been sunk on streaks of very light-colored rock, and have thus made exposures in which one can see plainly that the bleaching proceeds outward from simple fissures. These run in various directions, but the most marked among those observed have a general northwest-to-southeast course. They sometimes have quartz or other vein matter in them, but are often mere cracks, and the degree of alteration of the andesite decreases rapidly from the fissures outward. Where there is a system of parallel fissures or a complex of intersecting cracks the rock is naturally much changed.

Down to the little knoll at the north base of Mount Robinson there is no apparent variation in the rock composing the plateau. Here there is a breccia which has been so entirely decomposed, with a quartzose product, that the nature of the original rock can not be ascertained. It is probably the Bunker andesite, however, or possibly a dike of rhyolitic breccia, the latter alternative being suggested by the observed greater tendency of rhyolite to produce such quartzose material in this region, and by the proximity to the dike of Mount Robinson, which is thus altered.

KANKAKEE HILL AND VICINITY.

The area included under this heading lies northeast from Robinson Plateau, between Bunker Hill and Mount Tyndall, and is connected with the plateau by an irregular curving ridge.

Kankakee Hill and hills to the eastward.—This small tract is one in which the rocks are most thoroughly decomposed, scarcely an outcrop of fresh rock remaining. There are naturally a great many prospect shafts and tunnels in such an area, and these have demonstrated the prevalence in depth of the decomposition indicated by the surface rock. The course of the decomposition was primarily a bleaching, but it has been carried much further in many places, resulting in muscovitization and in secretion of quartz or carbonates in seams and cavities, and has locally caused a thorough obliteration of the rock structure.

Deposition of ore minerals has also taken place, and the white rock is often impregnated by minute pyrite crystals. Veins of quartz with more or less barite, calcite, dolomite, pyrite, chalcopyrite, blende, and rarely other minerals, are extreme forms of the secondary action. These deposits are seldom rich in silver minerals, however, and nearly all the locations here are now abandoned.

The less decomposed rock of this area is apparently the Bunker andesite, a part of the main mass of the hills. Underneath it is probably some Rosita andesite, breccia, or tuff, as the case may be, but it is impossible to locate the line between the rocks, owing to the fact that the Bunker rock is not infrequently brecciated, as seen in many prospects at horizons much above the probable limit of the other andesite. A number of shafts at the eastern base of the hill opposite Bassick Hill show that the Rosita andesite tuff is present in a very thin and irregular deposit between the Bunker andesite and gneiss. The latter outcrops at and below the Empire State shaft. The detailed geology of this border between the Bunker andesite is given in discussing the

Bassick andesite, and the data afforded by workings are contained in the section accompanying the enlarged map of Mount Tyndall and Bassick Hill.

The ridges north of Kankakee Hill.—The low ridges which branch off from Kankakee Hill on the north contain the key to the relations of gneiss, Rosita breccia, and rhyolite in this vicinity. By the outlines given on the map and by Section D, Pl. XXX, it will be clearly understood that the rhyolite is a detached remnant of a surface body which for the most part rests upon a bed of dark-reddish tuff belonging to the Rosita andesite. In places the rhyolite overlaps the red tuff, and comes to a direct contact with gneiss at the end of one of the ridges, while its boundary line toward Kankakee Hill meets the Bunker andesite. The latter also overlies the Rosita tuff, as is shown by one or two shafts which are sunk in the Bunker andesite shortly above the rhyolite contact and penetrate the reddish-brown mud material.

The contacts of the several rocks are fairly well shown, and shafts and tunnels prove the relationship to be about as represented in the sections of Pl. XXX. The interpretation of these facts is that the loose fragmental material belonging to the Rosita andesite formerly covered this region, lying upon an uneven surface of gneiss and granite. Erosion prior to the outpouring of the Bunker andesite had already reduced its thickness very much, while before the rhyolite effusion both rocks were worn down to the surface upon which this rhyolite sheet rests.

The rhyolite of the main ridges is fresh enough to preserve the spherulitic structure, and some of the best illustrations of various growths of spherulites were obtained from material near the end of the eastern ridge, from a horizon in the flow which could not have been more than 25 feet above the red tuff.

The straight western line of the rhyolite is probably due to a small fault. West of it is a considerably greater thickness of breccia and tuff than is seen to the east. A shaft sunk in red breccia a few feet west of the rhyolite line, halfway down the western ridge, penetrates gneiss at 58 feet in depth.

BUNKER HILL—SUGAR LOAF.

Bunker Hill and the Sugar Loaf are two of the most regular conical hills of the region, rising at the ends of ridges connecting them with the higher central portion of the Rosita Hills on the south. Their round tops and the connecting ridges are mainly made up of the Bunker andesite, while between them, forming Excelsior Ridge, is a mass of rhyolite. It is evident that prior to the rhyolite eruption a valley existed between Bunker Hill and the Sugar Loaf whose slopes were steeper than those of the present hills. It is probable that a local vent is the source of this rhyolite, yet it may have come from one of the large channels farther south—the Mount Robinson dike, for instance—that part of the Rosita Hills having then been relatively much higher than at present.

Bunker Hill.—The slopes of the hill are for the most part covered by slide, through which small outcrops of solid rock project here and there. Many prospect holes give data, however, so that the formation lines can be drawn quite accurately.

The lower northern and eastern slopes present brownish breccia, very much decomposed, but plainly a continuation in increased thickness of the Rosita andesite rock seen underlying the rhyolite north of Kankakee Hill. This breccia is massive, like that about Rosita, and seldom contains fragments of gneiss or granite. It continues around the southeastern slope of the hill and nearly up to the saddle, being here much bleached, and distinguishable from the Bunker andesite only by its fragmental character. On the northern slope the breccia has the purplish tinge characteristic of the Rosita breccia, and some shafts have penetrated to reddish mud or tuff material above the gneiss, though none have reached the latter formation.

On the western slope of Bunker Hill a white rhyolite breccia comes up to a sharp contact with the Rosita breccia or the Bunker andesite, along a line which is closely defined by prospect holes, though the contact is covered by andesite slide rock. The rhyolite line turns west to Carolina Gulch at the end of the spur below the Del Monte mine [7].

A narrow dike of mica-andesite cuts the rhyolite breccia on the west slope of the hill, and there are a number of small seams and veins of quartz and barite with galena and sphalerite which have been opened up by prospects.

Above the rhyolite and breccia, the top of Bunker Hill is composed of the augite-hornblende-mica-andesite which has been described, and to which, for convenience, the local name "Bunker andesite" has been assigned. It here appears as a greenish-brown, fine-grained rock weathering into sherdy fragments which form the even débris slopes.

Between Bunker Hill and the main road to the north is a knoll of rhyolite overlying the red mud and tuff which can be seen along the eastern base, and which are also shown at a small depth in the Mapleton shaft at the western base of the knoll.

The ridge connecting Bunker Hill with the Robinson Plateau is made up of extremely decomposed rock, most of which is referable to the Bunker andesite, though the Rosita breccia extends along its eastern base. The eastern slope has some outcrops, but the western is almost entirely covered by low timber or slide rock. The crest shows white rock, thoroughly kaolinized, with quartz in seams and sometimes in veins several feet wide, carrying sulphides of copper, iron, lead, and zinc to an extent which has led to much prospecting, with little result as regards precious metals. A trachyte dike running parallel to the crest of the ridge on its western side is exposed in a number of prospects.

West of this ridge is a minor spur from the south, upon which the Del Monte mine is situated. Above and back of the main shaft [7] is a patch of apparent rhyolitic breccia, nearly all changed into quartzose matter, and the shaft is sunk largely in cavernous quartz, carrying galena, pyrite, etc., some of which seems probably derived from alteration of rhyolite breccia. As the mine was already abandoned when visited in 1883, and no trustworthy data could be procured regarding the form or extent of the vein, it remains uncertain whether this body of rhyolite represents a remnant of a surface mass or a dike. If the former, then the underlying andesite has been altered to similar material.

Excelsior Ridge.—This ridge branches off from the eastern slope of Lookout Mountain and thence extends midway between the Sugar Loaf and Bunker Hill. At the upper end are two knolls of distinct Bunker andesite, but below them is rhyolite, which is much decomposed near the knolls and on the slope toward Carolina Gulch. The rhyolite is seen in comparatively fresh and normal condition on the slope toward Sugar Loaf, and well down toward the end of the ridge. It is there a light, almost white, rock with banded and spherulitic structure, but usually brecciated. Farther down, in the low parts of the ridge near the road, it is less massive and firm, and contains some small fragments of red andesite or of gneiss, thus grading into the tuffs seen on the outlying ridges north of the hills.

The alteration to which the rock has been subject in the upper parts of the ridge has produced the usual cavernous quartzose material in some places and softer kaolinized matter in others. With the former is usually more or less barite, and the whole is impregnated with sulphides, or there is vein formation, the two developments being evidently phases of the same secondary action. Where the alteration has been in mass, there are projecting cliffs or knobs, as opposite Bunker Hill and near the andesite knolls.

A much decomposed trachyte dike is seen in one or two places on the eastern slope below the knolls of andesite.

Sugar Loaf.—This rounded hill is in a measure the counterpart of Bunker Hill. Its round top is massive and moderately fresh Bunker andesite. On the east, rhyolite breccia like that of Excelsor Ridge comes well up on its slope and up into the saddle on the south. Here a shaft sinks through rhyolite into the underlying andesite at a depth of less than 40 feet. The rhyolite extends over the west side of the saddle, but its irregular outline and slight depth in the saddle show that it is merely an arm of the surface body which filled in a depression south of the Sugar Loaf corresponding somewhat to that of the present day. A similar arm of rhyolite curves partially around the knolls at the head of Excelsior Ridge.

The northern and western slopes are of Bunker andesites. At the northeast base is a small andesite knoll on the rhyolite border, and a rather coarse-grained trachyte dike cuts both rhyolite and andesite.

THE WESTERN FRONT OF THE HILLS.

The front presented by the Rosita Hills toward the northwest and west is less cut into by prominent gulches than is any other portion. The reason for this lies in the more continuous and massive development of a single rock—the Bunker andesite—than is found elsewhere. From the Querida road north of Lookout Mountain to the Rosita road near Rattlesnake Hill there is no gulch penetrating far into the hills, such as may be seen on all other sides, and along this line, following the crest, the Bunker andesite is the only rock appearing until the hill near the Rosita road is reached.

Lookout Mountain ridge.—Lookout Mountain is a high point on the western edge of the hills southwest of Sugar Loaf. Excelsior Ridge, which has already been described, springs from its eastern slope, a small saddle separating them. To the north it sends out a narrow ridge, which marks the western limit of the eruptives in this direction. The crest and eastern slope of this ridge are composed entirely of Bunker andesite, and this rock ends in a knoll on the north side of the Querida road, where it is surrounded by the valley wash.

The west slope of the ridge and of Lookout Mountain is very steep and is covered with andesite slide rock; hence the exact nature of the contact with gneiss, which runs high up on the slope, is not clear. The unusually fresh condition of the andesite here has deterred prospectors from explorations that might have exposed it. The line between the andesite and gneiss is so sharp and straight as to suggest a dike or fault contact, but it is probable that this body of andesite is merely a part of the surface mass of the Bunker type, for no evidence of a fault was observed.

On the western slope of Lookout Mountain proper a strip of rhyolitic breccia appears between the andesite and gneiss. Southward this body widens, and, extending down the slope, is found as a distinct surface flow upon the gneiss of the ridges which spring out from the southern spur of the mountain. This rhyolite is much like the breccia of Sugar Loaf; and when it is noted that only a narrow ridge 100 feet high separates the rhyolite south of Sugar Loaf from that on the west slope of Lookout Mountain, the conclusion is natural that these are parts of the same surface mass, and that the breccia seen on Lookout Mountain is merely a thin sheet clinging to the steep western slope of gneiss and andesite existing at the time of the rhyolite outbreak. The andesite slide rock conceals the contacts on the upper slopes.

From Lookout Mountain a narrow divide, with several rough knolls on its crest, runs southeasterly to the Robinson Plateau. It is formed mainly of rather fresh Bunker andesite, and serves as a watershed between the gulches eroded out of the decomposed softer rocks on either side.

About opposite the center of this ridge, on the south side, rises an unnamed point with an elevation of 9,535 feet, and from it branch off three ridges, upon which are located the points called Mount Fairview, Iron Hill, and Knickerbocker Hill.

In all the area about Lookout Mountain the Bunker andesite appears as a single mass, the original contacts of which are nowhere exposed, though quite closely defined on the western slope. It varies but little in texture, and is fresher here than elsewhere, though bands of bleached or much decomposed rock traverse the mass, and some mineral-bearing veins have been explored by shafts and tunnels now abandoned.

Ridges leading to Knickerbocker and Iron hills.—Of the three ridges mentioned above, the westernmost leads to the rough point called Knickerbocker Hill. The Bunker andesite forms this ridge down to the hill at its end, and presents in its various stages of decomposition nothing essentially different from what is seen in the areas already described.

Knickerbocker Hill itself presents a double-pointed top, the northern one consisting of the Bunker andesite in much bleached condition. At the northwestern base of this point some prospects show the andesite silicified and kaolinized to a degree destroying the original structure. The second point is rough, with irregular projecting outcrops on its southern face, characteristics due to the wide metamorphosed rhyolite-breccia dike cutting through it. The rock is the peculiar rough quartz and feldspar mixture which has been described in Chapter II as one of the extreme products of decomposition of rhyolite. In Knickerbocker Hill it is scarcely possible to find any rock showing the original rhyolite structure, and actual evidence of this origin for the mass was found only in the hill across the gulch at the southeastern end of the dike. At this point, south of Iron Hill, the dike is shown in contact with augite-diorite and Bunker andesite, and is not so completely decomposed as in Knickerbocker Hill. On the contact with diorite a shaft shows breccia containing some gneissic fragments. The eastern end of the dike is at about the gulch level southwest of Mount Fairview. A tunnel into the dike from that end shows the thorough decomposition there.

This dike and the similar one of Mount Robinson are now exposed as they cut andesite of the hills, while on the adjacent lower slopes are rhyolite surface flows which doubtless came, in part at least, from these channels. Barring the influence of faults between the dikes and the flows, no evidence of which was found, the relationship seen indicates that the Rosita Hills were high and presented very rough slopes on all sides at the time of the rhyolite eruption.

To the north of the eastern end of this rhyolite dike lies Iron Hill, which together with the ridge above it is made up of Bunker andesite, for the most part much decomposed. The name of the hill originated in the presence of a body of magnetite and pyrite, explored by shafts and tunnels at the Iron mine.

South of the rhyolite dike the Bunker andesite is cut by an irregular dike-like mass of Fairview diorite. It forms the second point of the hill, and projects in black outcrops at various points on the western and southern slopes. In general it is much fresher and more prominent than the bleached Bunker andesite. The outlines of this body are not accurately represented upon the map, for the rock is extremely variable in texture and is distinguishable from the andesite with great difficulty when both are bleached. The main error in the representation probably lies in making the dike so massive, as it is more likely to consist of several branches. In the Bunker andesite of the slopes west of this hill are several small dikes of rock which may be identical with the diorite.

At the southern base of the eastern point of this hill the augite-diorite exhibits several distinct modifications described in the preceding chapter. One of them is the coarse rock, rich in plagioclase, and another is the peculiar felsitic contact zone, consisting largely of quartz and orthoclase. The western end of one of the large trachyte dikes cuts the diorite on this slope.

Mount Fairview.—The third ridge which branches off from the point near Lookout Mountain runs nearly south, and is more irregular than the two which have been described. All the upper portion is of Bunker andesite, but in Mount Fairview this rock is cut by the peculiar augite-diorite whose different facies are so interesting from a lithological standpoint.

In Mount Fairview the Bunker andesite is nearly fresh in many places, and the contrast between it and the diorite, as seen in some contact zones and in small dikes, is very slight and can be followed only foot by foot. The summit is of andesite, but the diorite makes very prominent outcrops on the eastern slope in the spur shown by the map. Here the diorite is a black, fine-grained rock, appearing in quadrangular blocks through jointing planes. This is the olivine-bearing augite-diorite, while on the north border of the outcrop, about 100 feet away, the rock becomes orthoclastic and free from olivine, with some development of hornblende. It is also there cut by coarse-grained veins composed of quartz and feldspar. As in the hills to the westward, the outlines of the diorite are not known accurately.

Paris Hill.—The eastern point of Paris Hill is made of comparatively fresh Bunker andesite. From Mount Fairview a small dike of augite-diorite cuts irregularly through the main point, and after following the ridge to the southwest for some distance, turns down the western slope, passing under débris. It very possibly connects with the body of the hill to the west, but this could not be established. Efforts to trace out the contacts of this dike, made after the lithological differences were understood, showed that it could be done at all only where the outcrops were very distinct, and by close examination of the freshly fractured rock. The weathered surfaces of the two types can scarcely be distinguished.

The southern slopes of Paris Hill are composed of more or less bleached Bunker andesite, and across them pass at least two important dikes of trachyte which are continuous to this point from the region of Rosita. They are almost wholly decomposed, but their structure and the occasional remnants of glassy sanidine which may be seen identify the rock at a glance.

The contact of the Bunker andesite with the very similar Pringle andesite seen in the Rattlesnake dike is one of the features of the hills which was most puzzling on first examination. This will be referred to in the description of the Rattlesnake dike.

AREA BETWEEN GOOD HOPE AND LEAVENWORTH GULCHES.

Democrat Ridge.—This name is applied to the very straight ridge with several knolls on its crest which forms the eastern bank of Good Hope Gulch, from the west end of Robinson Plateau to Democrat Hill. The ridge is made of Bunker andesite, generally in very much bleached and decomposed state. Dikes of trachyte with east-to-west course cross the ridge at various places. Excepting, however, for the large ones near its lower end, these dikes are not traceable for any considerable distance and are not shown upon the map.

At the spur opposite Mount Fairview the augite-diorite appears in comparatively fresh form, and is cut by a dark trachyte dike having dense porphyritic structure and almost black contact zones.

Just north of Democrat Hill the andesite is cut by the long trachyte dikes from the east, and here the decomposition is so marked that rock structures are lost entirely. The trachyte dikes themselves are quite distinct, and the rock is locally fresh enough to allow of identification aside from the evident continuity of the bodies. Between them, however, the andesite is locally transformed into quartzose material, and it is only by tracing the transition into distinct andesite that the nature of the original rock can be made out.

Democrat Hill.—This is one of the most interesting masses of the region, and its study has given much information concerning a very important phase in the history of the Rosita volcano.

The upper part of the hill is exceedingly rough, presenting crags of hard, light-reddish or mottled rock strongly resembling the forms characteristic of granite. This rock is the peculiar quartz-alunite mass described in Chapter II, which has resulted from the action of solfataric vapors upon the rhyolite at and near the surface. Large blocks of the alunite rock cover the lower slopes of the hill.

About the base of the rougher cliffs, and in smoother places between them, a soft earthy rhyolitic material is exposed, much of which exhibits some spherulitic structure. In the prospect holes sunk on the slopes there is often some white kaolin-like matter, and rarely a little vitreous rock, crumbling because traversed by fissures filled with kaolin. The surface, however, furnishes but little clue to the real make-up of the hill, so thoroughly are the slopes covered by débris.

The workings of the Ben Eaton and Democrat mines show the internal structure very well. The main tunnels of these mines enter the hill at its southern base, running parallel to one another nearly due north. The Ben Eaton tunnel [18] enters the hill in a trachyte dike 3 to 6 feet wide, the rock of which is so decomposed as to make no outcrops above on the hill. Its contacts afford smooth, perpendicular walls for the tunnel, which follows it in somewhat curving course for about 500 feet. The Democrat tunnel follows the west wall of another trachyte dike, which is somewhat thicker than the first, for about 435 feet. From this point a crosscut is made to the Ben Eaton tunnel, and from both tunnels there are drifts running at various angles.

The workings of both mines when not in the trachyte dikes are in more or less decomposed rhyolitic material of varied character. Some is rather massive; much is more brecciated and still shows spherulitic development. All is kaolinized, or locally silicified, and the changes in constitution seem to indicate an original banding of irregular character. In many places distinct spherulites several inches in diameter are found embedded in soft, white kaolinite, which was shown in the preceding chapter to be a frequent alteration product of pitchstone in this region. Remains of interspherulitic glass were seen in a few cases.

By means of an upraise the trachyte dike of the Ben Eaton was traced to the surface and the ready erosion of this soft material was found to be the cause of a cleft in the alunite rock of the crest of the hill. A cross drift shows another trachyte dike west of the one followed by the Ben Eaton tunnel. The fact that the trachyte rock is not altered to alunite is pretty definite evidence that the solfataric action immediately followed the rhyolitic eruption.

While the structure of this hill is not well shown, it is clear that it represents a large eruptive channel or conduit, through which several eruptions of rhyolitic magmas occurred, and that the solfataric action was the last phase in this period of the volcano. No gneissic fragments or strictly tuffaceous material corresponding to that of Wakefield Hill were observed here, and it may be that explosive activity was not shown at this vent. The similarity of the rhyolite to that of adjoining flows south of the Rattlesnake andesite dike makes it extremely probable that some of them came from this vent.

Concord Hill.—This spur of Democrat Ridge represents in its mass about the extreme of decomposition of the Bunker andesite. In this immediate area the whole rock is bleached, and most of it kaolinized or muscovitized until it has lost the general structure of a rock mass and become more like vein matter. Quartz, barite, etc., impregnated with sulphides, are found all over the hill, and while usually occurring in seams and veins, the rock mass is locally so much altered as to be practically of the same constitution. This decomposed rock is referred to the Bunker andesite more from its position than from any identification of the rock. The hill comes within the range of the broad zone extending up the slope of Mount Robinson, where the line between the

Rosita and Bunker andesite lies, but is nowhere definitely determinable, owing to the prevailing extreme alteration of both types.

The southern slope of the hill is cut by a large trachyte dike, and there are several smaller ones.

PRINGLE HILL AND VICINITY.

The area to be considered here embraces Pringle Hill proper, the unnamed point lying west of it, and the slopes to the southward as far as the limits of the main mass of Pringle andesite, just north of the Silver Cliff-Rosita road. By glancing at the map it will be seen that a large mass of Pringle andesite occupies the greater part of the area, resting upon Rosita andesite which appears on the eastern and northern slopes. Several large trachyte dikes cut through the hill, and a small patch of rhyolite appears near Rosita Creek, north of Pennsylvania Hill.

Area occupied by Rosita andesite.—The Rosita andesite, in the various textural modifications which have been referred to in describing the region about Rosita and Mount Robinson, is well shown by outcrops and by prospect holes all over the lower portions of the northern and southern slopes of Pringle Hill. From the divide near the Leavenworth mine there are many good outcrops of very typical rock up to about the line of the Pringle andesite, which is obscured by the growth of aspens, pines, etc., commonly found on the northern slopes of these hills. Near the Alexander and Invincible shafts the rock is found in comparatively fresh condition.

On the eastern slope, which is shown in Pl. XXXII, the débris of Pringle andesite from the top covers much of the Rosita breccia near the contact, but lower down the latter rock is seen in many outcrops. The numerous prospect shafts and tunnels which have been driven into the Rosita andesite all over this hillside give evidence of the variable texture of the rock mass. On Pringle Hill may be seen nearly all of the modifications of this type which were described in Chapter II. Some of the prospects have encountered the normal breccia of bluish-gray color; others penetrate more tuffaceous material, which ordinarily crumbles by exposure on the dump. Granite and gneiss fragments are sometimes found here, though several hundred feet in thickness of Rosita breccia must be present below the level of Rosita Creek.

Locally the tuff is so fine-grained that it comes under the designation *mud*, applied in the rock descriptions to parts which by mixture with water have evidently had a consistency allowing a flow movement. Probably certain of the lower horizons of the tuff remained in this plastic state for a long time, or they may have been repeatedly softened by the accumulations of surface water in them. In periods of violent earthquakes, attending later eruptions, this plastic material would naturally be injected into fissures in the overlying rock and would now appear as dike or vein-like masses. Such veins are now visible in various places on Pringle Hill and elsewhere. The substance filling the fissures is usually very dark red-brown in color and compact and homogenous in outward appearance, but is found on careful examination to be fragmental and like the finer tuffs to be found in the andesite complex. Good examples of these mud veins occur on the eastern slope, below the point on the southern ridge of the hill and near the rhyolite mass.

Besides the massive parts of the typical Rosita andesite, there are some small patches of dark compact rock seen on the eastern slope of Pringle Hill which are not mineralogically identical with that type, as they are more pronounced pyroxenic forms, and are usually coarser grained. They are much fresher, too, than the prevalent type, and it seems most likely that they are later injections of some other andesitic eruption, although they are not identifiable with any of the other varieties described.

A dike of dark-reddish andesite some 40 feet wide runs down the slope toward Pocahontas Hill. It is too much decomposed for identification, but seems most like a dike of the Rosita andesite itself, belonging to one of the later eruptions of the series which must have occurred in that period.

The mass of Pringle andesite.—The top of Pringle Hill, its entire western slope, and the hills to the west of it are made of what seems to be a single mass of an augite-mica-andesite which is considerably younger than the Rosita and the Bunker types, being separated from them by the period of the rhyolite outbreaks, the lavas of which are cut by its dikes.

The rock is as a rule rather dark gray, of distinct porphyritic structure, the grain of the groundmass being much coarser than in the Rosita rock. It is massive throughout and comparatively much fresher than the andesite of the other predominant types. The outcrops are numerous, and a large part of the area is covered by small, sherdy fragments resulting from the weathering of exposed parts. Excepting in the small basin in the center of the area, there is but little surface covered by soil.

While the Pringle andesite is not so thoroughly decomposed as the adjoining rock masses, it is traversed in all directions by fissures, near which it is bleached in the manner seen in other rocks. The feldspars are muscovitized and the darker silicates destroyed, but in few places is the rock so changed as to obliterate the structure. Ore deposition is rare within the mass of this rock, yet some fissures near the summit of the hill contain iron and manganese oxides which have to some extent replaced carbonates, possibly of the same bases.

It will be observed that the boundaries of the mass as represented by the map are unusually regular and inclose an almost rectangular area. Lines so independent of topographic forms can belong only to planes which are nearly vertical, and in such a case they are likely to be either natural contacts of the andesite cutting up through the country rock, or fault lines. The size and form of the mass make it improbable that its present boundaries can be of the nature of dike contacts. If it is not a dike the interpretation of its straight outlines as fault lines of structural importance is demanded as an explanation, in the first place, of the form of the mass as part of a surface flow, and in the second place of its relationship in point of level to the dike of the same rock which comes almost in contact with it on the western border. As a matter of fact, the contacts actually seen are mostly fissures upon which there has certainly been some movement, though no data exist upon which an estimate of the amount of displacement can be based.

The eastern line of the Pringle andesite is exposed at the base of the prominent knoll south of the summit, where the small ridge branches off to the southeast. A shaft is here sunk on a fissure showing the massive Pringle andesite on the west and dark-red material belonging to the Rosita andesite on the east. This latter material is largely an attrition matter produced by a faulting movement, as is shown by the small fragments of rhyolite spherulites contained in it. Rhyolite approaches on the surface to within a few feet of this contact, and no doubt meets it not far below. The fault plane is nearly vertical, wavy, exhibits slickensides, and has a strike northward, as indicated on map. It is not shown north of the spot mentioned, owing to slide rock, but the Rosita andesite is shown in place nearly up to this line at several points, and solid outcrops of the other type appear above it. It follows closely the base of the steeper slope of the top and doubtless is the cause of the same.

Southward from the shaft mentioned the line of contact curves slightly to the westward and is shown in several places as a sharp line between the andesite and rhyolite, the latter a tuff carrying fragments of granite and of massive rhyolite. The fault shown here in prospects is compound, consisting of a number of parallel fissures, on each of which there has been some movement, and the massive andesite on the west is also sheeted by pressure for several feet from the fault.

The boundary of the andesite runs nearly down to the level of the valley and then swings rather abruptly to the westward. The end of the little ridge opposite Pennsylvania Hill is of rhyolite breccia consisting of small angular fragments of dense or spherulitic rock. This material, breaking into sherdy fragments, continues for about 150 feet from the road. Then follows soft, white, tuffaceous material similar to that of Wakefield Hill, and carrying fragments of gneiss and granite and of dense rhyolite with fluidal banding. At 200 feet from the road the contact of the Pringle andesite appears, dipping steeply northward, with dark-reddish mud-like stuff on the south. This seems like Rosita tuff except for small rhyolite fragments in it, and it probably does represent such material broken up and mingled with products of the rhyolite outbursts.

North of the cemetery the boundary of the Pringle andesite turns more nearly to an east-and-west course, which is followed with minor bends to near the patch of gneiss represented on the map. For a part of this distance the limit is a complex vertical fault line, which is shown in three prospect holes but a few feet north of the road. As on the east side, there are several undulating planes with crushed rock between them, the solid Pringle andesite on the north and a breccia on the south. All rocks adjoining the fissures are much decomposed.

From the general features of the local geology one would be inclined to suppose that the movement on this fault might have been considerable, and thus account for the small area of gneiss and the mixture of rocks in the space south of the fault line, which are unlike those seen elsewhere. But the southwestern point of the Pringle mass seems to cut into the rhyolite breccia in a manner which is difficult of explanation through faults, and thus a part of the contact of rhyolite and andesite is probably primary.

The western boundary of the Pringle mass can be followed along the slope of a ridge which is a distinct outcrop of andesite, and the rhyolite to the west is also plain, while the actual contact is covered by débris. On the eastern side of the saddle at the end of the Rattlesnake dike a prospect shaft is sunk on a fault line having massive Pringle andesite on the east and on the west a fragmental material in which there is gneiss as well as andesite and rhyolite. This fault plane is in the strike of the andesite boundary to the south. North of this saddle, on the slope facing Leavenworth Gulch, there are no outcrops near the probable boundary line, and the course of the fault is not elsewhere known. It passes into the region of altered Bunker andesite and can not be identified.

The northern boundary of the Pringle mass is concealed over most of its length, and it may not be so straight as represented, though it can not vary much from the line given. The line drawn represents the proved extent of the Rosita breccia.

The trachyte dikes.—Prominent features of Pringle Hill are the large trachyte dikes which cut through it in an east-and-west direction. The larger ones are represented on the map, but there are several others of small size and but little is known as to their course. These are often decomposed, and have thus attracted the notice of prospectors as vein-like masses.

The three prominent dikes cutting the highest parts of the hill are direct offshoots of the single body north of Rosita. The branching of this mass near the Maverick mine is quite plain. On crossing the creek the southern dike diverges somewhat from the others and runs with a slightly curving course up to the southern side of the saddle in the top of the hill and then down the western slope. It was not traced across the western branch of the hill. In the ravine at this point a tunnel has been driven eastward in the comparatively fresh rock, which here carries large crystals of pink orthoclase.

The two other large dikes on the eastern slope are somewhat irregular in their courses, uniting at a little distance above the gulch, but separating again very soon, and thence cutting through the northern point of the hill to the western base, where they again unite and as a single dike cross Concord Hill and Democrat Ridge, but branch again near Good Hope Gulch.

On the slope facing Pocahontas Hill are two prominent dikes, one of which is probably an offshoot from the northern dike at the top of the hill, though the junction can not be observed on account of slide rock. Still another dike runs down the ridge at the northwestern base of Pringle Hill, passing very near the Invincible and Silver King [19] shafts.

Nearly all the trachyte dikes of the hills belong to a system of contemporaneous fissures, the prevailing direction of which is that of the larger dikes of Pringle Hill, but minor ones running in all other directions may be seen as well.

The trachyte dikes cause slight projections on the slopes where they cut the Rosita breccia, and are easily traced where not concealed by heavy débris. The features of the contacts and the gradual changes in structure as distance increases from the main source near Rosita have been dwelt upon in Chapter II.

The fissures which served as channels for decomposing waters and those depositing ore minerals are plainly later than the trachyte eruption, as shown in Pringle Hill. The vein of the Maverick and Aspen mines cuts obliquely across the main trachyte dike in Hungry Gulch, and the small trachyte dikes all through the hills are subject to kaolinization in marked degree.

The rhyolite mass.—Opposite Pennsylvania Hill there is a small mass of predominantly white and very soft rhyolitic tuff making rather indistinct outcrops. The nature of the mass is not well shown, but from the character of the materials it must be considered as a filling of an eruptive channel probably directly connected with that of Wakefield Hill. The greater part of the rock shown is kaolinized, but parts are spherulitic or plainly fragmental and contain throughout more or less granite and gneiss in rounded fragments, as on Wakefield Hill. Adjoining the Pringle andesite south of the prominent knoll these bowlders are heaped up so abundantly that the whole was at first supposed to be an outcrop of granite.

None of the rhyolite on this side of the valley resembles the massive banded rock of Pennsylvania Hill; and as the alluvial deposits of the low ground conceal so much of the rock at this place, the relations of this rhyolite mass to those south of the creek can not be established. It seems probable on this ground, also, that a fault, such as the one south of the Pringle mass, runs nearly on a line of Rosita Creek, passing just south of the town and causing a part of the complication which plainly exists in this vicinity. Reference to this possible fault has already been made in describing Pennsylvania Hill.

AREA SOUTH OF THE PRINGLE ANDESITE MASS.

This little area is so largely covered by alluvium that it is hard to make out the true relationships between its several formations and the neighboring masses of similar rocks. Faulting must have had something to do with the complications, but to what extent can not be satisfactorily determined.

Exposures of gneiss and granite.—The northern limit of the area is the line of the Pringle andesite mass, a part of which at least is a fault contact. As stated in the preceding section, the movement on this fault seems to have been a downthrow on the north, and it is further most likely that there was a slight actual upthrow on the south, for the region on that side of the fault seems elevated with regard to the country on either side as well as with respect to the Pringle mass. This movement is indicated by the appearance of a patch of gneiss and by the character of the materials resting upon it.

The gneiss is exposed beside the Rosita-Silver Cliff road, thence extends southward as represented by the map, the southern lobe being mainly outlined from the observed distribution of gneissic débris. The rock is gray or reddish gneiss, dipping steeply northwest, in accord with the general structure of the gneissic series already given.

Between the gneiss and Pringle andesite is an arm of tuffaceous material of varying character, but containing some rhyolite throughout, with abundant admixture of reddish andesitic débris in some parts. This tuff band is much decomposed, and is probably traversed by a complex of little faults.

That the gneiss area is not merely the crest of a hill surrounded by the eruptives is further indicated by the western boundary, which seems to be a fault, and is probably a branch of that one forming the western line of the Pringle andesite mass. This fault is shown in a deep shaft at the extreme western point of the gneiss. The shaft is sunk on a complex of fissures with general northeast-southwest course, between which the gneiss is all crushed and so decomposed that it disintegrates to a gravel by exposure upon the dump. While no rhyolite is visible in this shaft, the contact is but a few feet away, and shafts a few yards to the westward are sunk in rhyolite for at least 50 feet without encountering gneiss. This rhyolite is massive, spherulitic, or tuffaceous, but in the latter case is free from andesitic débris, which characterizes the lowest horizons of the rhyolite deposits immediately to the eastward.

The other contacts of this gneiss patch are obscured by surface débris or soil, but they appear to be the lines where the gneiss disappears under eruptive masses resting upon it. To the south the bounding rock is rhyolite, on the east a dark andesite or a tuff like that on the north.

The andesite area.—The andesite appearing on the east of the gneiss exposure is colored upon the map as Bald Mountain dacite, since it appears to underlie the rhyolite, as in the adjoining district upon the east, and as it possesses the same structure. In mineral composition the rock of the western outcrops differs somewhat in having augite more abundant than either hornblende or mica and in the absence of free silica, as quartz or tridymite. But considerable variations in the composition of this rock were seen in the district south of Rosita, and the western exposures may readily be considered a part of the same mass.

The outcrops of this andesite are not prominent, as they occupy low ground and the rock breaks by weathering into small angular fragments. A distinct low ridge runs along the eastern border, from the cemetery southward, and quite solid rock is seen on the slopes of the little hill adjoining the gneiss patch.

Rhyolitic tuff.—The material covering the andesite on the east is tuff, assigned to the rhyolite period because there is always some rhyolite in it, and in many places it is nearly free from other rocks. This tuff seems to represent material thrown out by one of the first outbursts of the rhyolite period, and contains abundant andesitic débris, with little rhyolite in the lower horizons, while succeeding layers are richer in rhyolite. Natural exposures showing this sequence of layers do not occur, but it may be seen in a few prospect holes on the ridges east and south of the cemetery. Probably the vent which produced the greater part of this tuff is one of those penetrating Rosita tuff on the slopes of Pringle Hill. This would naturally account for the ill-defined reddish dust and gravel which is so prominent in parts of the tuff about the cemetery.

Considering the mixed fragmental rock as of this origin, and as having at one time covered the Bald Mountain andesite completely, we can interpret isolated patches of this tuff as thin remnants underlain by a continuous andesite mass. Of such remnants the only one represented by the map is the capping of the hill adjoining the gneiss patch. Other smaller areas probably exist over the region colored as andesite.

The fact that on the eastern side of Rosita Creek the rhyolite is massive, banded, or spherulitic, while on the western side it is mainly tuffaceous in character, suggests again the elevation of the area we are considering by a fault which might well be assumed as the prolongation of the one forming the eastern limit of the Pringle andesite mass. But this fault is not actually necessary, as will be seen by considering the uneven surfaces naturally existing at the beginning of the rhyolite eruptions and the removal of the early fragmental materials which may have taken place prior to the eruptions of the massive rhyolite lavas.

On the southern line of the map is a hill of banded and spherulitic rhyolite like the hills on the eastern bank of Rosita Creek, and at its eastern base is a small outcrop of andesite which has been connected upon the map with the area to the north. The northern base of this rhyolite hill is covered by an aspen growth, and it is not known whether the reddish tuff lies between the andesite and the rhyolite, as it should according to the views above expressed, unless it was removed by erosion before rhyolite was poured out.

THE RATTLESNAKE DIKE AND ADJACENT SLOPES.

In the remaining portion of the Rosita Hills there are no massive bodies of eruptive rock producing hills comparable with those which have been described. The Rosita Hills proper end in this direction in a line of smaller but still prominent points and knolls which for the most part are situated upon a broken ridge of general east-and-west course. This ridge and the prominences upon it are caused by a large dike of the Pringle andesite which extends for a distance of 2 miles, passing through Rattlesnake Hill—whence the name applied to the whole. Beyond this dike are only the low ridges of rhyolite which gradually merge into the valley slope.

The main dike and its branches.—The main Rattlesnake dike begins almost if not quite in contact with the Pringle mass in the saddle southeast of Democrat Hill. From here to Rattlesnake Hill its course is somewhat irregular, but it retains a width of 100 feet or more, and all but one of the prominent hills in this line are caused by it. The rock is compact, dark-brown, porphyritic, fresher than most rocks of the hills, and hence offers greater resistance to erosion. As a rule the slopes are to a considerable extent covered by slide rock from the dike, and, especially on the northern side, by soil, supporting in places a growth of small aspens and pines, so that contacts are not often exposed. It has been pointed out that a fault by which the large mass of Pringle andesite has been lowered runs across the end of the dike, and explains the otherwise anomalous position of the two rock masses.

The hill at the eastern end of the dike shows rhyolite in place on the south side up to the line indicated, but on the north no outcrops occur, and the rhyolite fragments in the soil and shown by shallow holes are the only evidence of the underlying rock.

Leavenworth Gulch cuts a narrow channel through the dike opposite Democrat Hill. Beyond the gulch to the westward is a short turn in the dike, and in this part are two knolls. Rhyolite is seen on both sides of the dike at this point.

A short distance west of Democrat Hill two small streams cross the course of the dike, but beyond this point it serves as a divide to the drainage of the area. About the point where the easternmost of these streams cuts the dike the Bunker andesite becomes the north wall of the dike, and there is no more rhyolite seen north of the dike until the second point east of Rattlesnake Hill is reached. For this distance the dike seems to run on the line between the rhyolite and andesite. Probably small patches of the andesite are attached to the south wall of the dike in places, but slide rock from the projecting dike hides them, if present, in all but one spot, soon to be mentioned.

From the second point east of Rattlesnake Hill to the western end of the dike it plainly cuts rhyolite, as represented, the walls being closely definable, though the contacts are not often seen.

In the middle part of the dike are many branches on the south side, and there may be some on the north, running off into the similar Bunker andesite, but if such exist they are well masked by slide and soil, and could not be identified after careful search. The development of small orthoclase crystals in the Bunker andesite causes it to resemble the Pringle dike rock very closely, and bands of comparatively fresh rock seem at first to be dikes of the latter type.

In the short distance between the point where the Silver Cliff-Rosita road crosses the dike and Rattlesnake Hill there rise four prominent hills or knolls, three of which are situated upon the dike, while the fourth and highest adjoins it upon the north. In this part of its course the dike sends off on the southern side several long, narrow branches and a number of short offshoots. There are, in addition, a few irregular masses and dikes not visibly connected with the main one. All of these bodies are clearly contemporaneous and represent a system of fissures and channels which unite at some depth and have been filled by the same magma. Owing to abundant slide rock on the slopes of the main dike and to local decomposition, the relationships of these rocks are in some cases not very plain; and although the representation of the map is based upon a close study of the locality, it is not probable that all the bodies are correctly outlined. They are separated by arms of white rhyolite, and thus could be easily traced out were it not for débris of andesite. The only place where there is much uncertainty as to the connections is within 200 feet of the main dike, and here some of the shorter offshoots may possibly be connected by narrow arms with dikes which seem to be isolated.

The main dike is somewhat irregular in this portion of its course, narrowing in two places decidedly. It passes through the summit of Rattlesnake Hill and down the western ridge, where it divides into two irregular branches, narrowing rapidly and apparently ending at about the gulch level west of the hill. In the rhyolite ridges beyond the hill there are ten or more narrow dikes of the Pringle andesite, the courses of most of them being nearly parallel to the Rattlesnake dike. They evidently represent the subsidiary cracks which may naturally be looked for near the end of a large fissure like that occupied by the main dike.

The slopes adjacent to the Rattlesnake dike.—To the north of the Rattlesnake dike there is but a narrow belt of country which has not been described in preceding sections. The Bunker andesite is the country rock south and southwest of Paris Hill as far as the dike. It is cut by two trachyte dikes, which unite in Good Hope Gulch to form one of the long ones traceable from here across the hills to the vicinity of Rosita.

The third point east of Rattlesnake Hill is made of Bunker andesite and an irregular body of Fairview diorite, which occurs at the summit. The outlines of this latter rock mass are not accurately known.

At the time of the field work the diorite was regarded as a facies of the prevalent Bunker andesite, and attention was directed mainly to distinguishing between the Pringle and normal Bunker andesites. The diorite mass occupies the summit of the point, and has a general form as indicated, but its contacts were not traced out in detail. On the south side of Rattlesnake dike a small patch of dense gray vein matter belonging to the diorite projects through the rhyolite; hence it appears that the dike cuts off a part of the diorite body. As usual, the diorite is fresher than the surrounding Bunker andesite. The latter rock, on the slopes northward from the diorite point, is bleached out for the most part, though fresh enough for identification.

To the south of the Rattlesnake dike the low ridges are composed exclusively of rhyolite for a short distance beyond the borders of the map, excepting for the andesite dikes already mentioned. The ridges on either side of Leavenworth Gulch are higher than those to the west, and present more massive forms of rock. Porphyritic varieties with distinct quartz, feldspar, and mica crystals may be found alternating with banded felsitic rock, and not infrequently with modifications carrying spherulites several inches in diameter. Pitchstone, usually reddish or yellowish in color, appears locally.

A short distance south of the line of the map a long tunnel is driven into the ridge on the northwest side of Leavenworth Gulch, and is almost entirely in pure white or delicate pinkish material, resulting from the decomposition of a bank of pitchstone overlain by massive earthy rhyolite. This substance is composed of kaolin and opaline silica, like that in the Fleetwood tunnel at Silver Cliff. The glassy rock from which the material is derived is shown in several places, and the various stages of the change can be seen almost as clearly as in the body near Silver Cliff, described in the preceding chapter.

The ridges south and southwest of Rattlesnake Hill are composed in a much larger degree of brecciated rhyolite masses than are the ones to the east, and the massive portions are more variable in structure. Small patches of pitchstone are found in irregular relation to the rest and containing small spherulites of great beauty, often of several periods of formation. The breccia rocks are seldom of pure rhyolite, for they include either gneissic fragments or reddish andesitic material. As shown west of Rattlesnake Hill, there is but a slight thickness of eruptive material lying on the gneiss, and it is evident in most places that there was a thin covering of reddish tuffaceous matter upon the gneiss at the time of the rhyolite outburst. It is also plain that at the beginning of the period of rhyolite eruption there must have been considerable explosive action, whereby the country was covered with ashes and with small fragments of spherulitic and banded rhyolite. These fell upon the reddish tuffs of the Rosita andesite, and, by means of water, which apparently accompanied the eruptions in floods, the two rocks became locally mixed in mud-like deposits or flows. At the southern and western bases of Rattlesnake Hill one may find the two rocks both separate and commingled in various ways in masses which were once mud flows or deposits in pools.

It is not uncommon to find twigs of charred wood or leaf impressions in the finer-grained mud deposits, and at the southern base of Rattlesnake Hill a dense, white, finely stratified rhyolite ash contains leaf impressions representing several species of trees, a list of which has been given. This fine-grained material is but a foot in thickness, and both rests upon and is overlain by coarser fragmental rock.

THE WESTERN BASE OF THE ROSITA HILLS.

A study of the band along the western base of the Rosita Hills shows that the present surface is very nearly like that which existed just before the rhyolite eruptions. The hills, which at that time were made up chiefly of Bunker andesite, doubtless rose much higher than they do now, and had more abrupt slopes, but they met the adjacent gneissic country to the north and west on a line corresponding to the present limits of the andesite. With this idea in mind, the character and relationship of the different eruptives seen on the ridges adjoining the hills will be easily understood.

Near Rattlesnake Hill.—West of Rattlesnake Hill is a small area of gneiss nearly surrounded by rhyolite. On all sides it is seen that the rhyolite rests upon gneiss, is for the most part breccia, and often contains gneiss fragments. While the greater portion of the rhyolite probably came from the vents in the Rosita Hills, a short dike of white, fine-grained porphyritic rhyolite in the most prominent knoll of the gneissic area shows that local sources also existed for a part of it. Rock of exactly the same structure is found on one of the ridges east of this knoll, indicating that the gneiss hill represented by this area rose but slightly higher than at present, and also that the local eruption was contemporaneous with the general outbreak, its products mingling with those from the more important channels. Several syenite dikes with northwest-southeast trend cross this area.

On the ridge east of the knoll with the rhyolite dike the first rock found resting on the gneiss is a dull-green felsitic mass, which the microscope shows to be a devitrified pitchstone, the decomposition having proceded from perlitic fissures still to be recognized. Above this comes the usual rhyolitic breccia. This green felsite appears at several places in the vicinity, always near the gneiss, and doubtless all belongs to one eruption. At one spot this greenish rock is vesicular, the pores containing the rare zeolitic mineral ptilolite.

On the next ridge to the north the rhyolitic covering is succeeded by one of Pringle andesite. The rock is very dark reddish-brown in color, fine-grained, and almost identical with the rock of the narrow dikes of the region. A fluidal structure is apparent near contacts, and small fragments of rhyolite are caught up in it in some places. The vent through which this lava reached the surface is shown at the upper end of the mass. Here, in a rhyolite knoll close by the Rosita road, an arm of the body is seen to be a dike cutting up vertically through rhyolite. Whether the southern arm of the andesite outcrop is a dike or not is not clearly shown, but it appears to be one. From this occurrence one must conclude that prior to the eruption of the Pringle andesite erosion had again restored the surface to an outline very near to that now seen.

How much of the Pringle andesite was poured out covering these slopes we can not tell, but trachyte dikes are seen cutting gneiss, rhyolite, and both Bunker and Pringle andesites of this immediate vicinity. One of them runs along the southern part of the gneiss outcrop and is seen crossing the rhyolite boundary. Another cuts the southern arm of the Pringle andesite mass near the Rosita road.

The Bunker andesite of the ridges north of Rattlesnake Hill is seldom fresh, and in some localities is so white and soft from kaolinization that it greatly resembles the denser earthy forms of rhyolite. The ridges are smooth and the banks of the shallow drains between them afford but few good outcrops. By the aid of the numerous prospect holes the boundary line can be followed pretty closely.

West of Lookout Mountain.—On the ridges leading from Lookout Mountain toward Round Mountain the deposits of the valley slopes are thicker than on either side, and conceal the rhyolite sheets, so that but a narrow zone is seen at the base of the steeper andesite slopes. Here are several dikes of dark andesite cutting the rhyolite, which are more nearly related to the Pringle andesite than to any other of the prominent types, but seem, from grounds given in the preceding chapter, to belong to a period of eruption later even than the trachyte. Other dikes are apparently of the Bunker type.

West of the andesite mass of Lookout Mountain and of the ridge running north from it the rhyolite runs up the steep slope and wedges out as a narrow strip between andesite and gneiss. It is deemed probable that the rhyolite mass was once continuous over this ridge, connecting with the mass of Sugar Loaf. Opposite this point there is a group of rather rough gneissic hills and ridges from which all surface flows of eruptive rocks have been removed, but, unless there has been dislocation through faulting, it would seem plain that this area must have been covered to some extent by the rhyolite. A few dikes of the Bunker rock were seen in these hills, and remnants of the Rosita tuff and of rhyolitic material may still be found under the wash of the lower slopes adjoining them.

THE NORTHERN BASE OF THE ROSITA HILLS.

To the northward of the hills the rhyolitic flows and fragmental rocks extend out only upon the ridges on either side of Carolina Gulch. Farther eastward the gneissic hills are high and were possibly never covered with any considerable quantities of the eruptive rocks.

The ridge showing the greatest amount of rhyolite is that forming the continuation of the divide running north from Bunker Hill. For a distance of about a mile from that hill the rhyolite of this ridge, forming the right bank of Carolina Gulch, is made up of nearly pure rhyolitic breccia, with a little massive rock. Patches and irregular vein-like masses of pitchstone occur quite abundantly in the knoll adjoining the Querida road.

On the left or western side of Carolina Gulch, and south of the Red Spring, there is a thin coating of rhyolitic tuff upon the gneiss, but here, as in the region south of Rattlesnake Hill, there is a varying amount of the Rosita andesite tuff and mud present between the rhyolite and the gneiss. This loose material has been mixed with the fragmental rhyolite rocks in a marked degree, so that pure rhyolite tuff or breccia is seldom found on this bank of the gulch or on the northern side about the Red Spring. Surface materials cover these low ridges, so that there are no extensive outcrops, and the character of the mixture of rhyolite and andesite changes so rapidly that scarcely two outcrops or prospect holes reveal the same material.

At Red Spring, situated in Carolina Gulch about a mile north of Sugar Loaf, is the best instance, showing the character of the red tuffaceous deposit which probably covered the entire region to a considerable depth at the time of the Rosita andesite eruption and for some time thereafter. The north bank of the gulch at this point is made up of a fine, uniform, red mud, overlain by loose rhyolite material, with which the former is admixed to some extent. The red mud is here of much greater thickness than in any other place known. It is penetrated by the tunnel for 270 feet, and from that point an incline with a dip of 20° continues for 97 feet. A shaft meets the incline at its lower end, at 64 feet from the surface, and is sunk 36 feet farther in the mud. On the bank of the gulch northwest of the tunnel and not far from the apparent end of the eruptive materials a shaft is sunk 50 feet in the mud. These data show that there was a depression, probably of the nature of a valley, filled with this originally ash-like material, which has escaped erosion by some chance. The mud is of very uniform composition throughout.

III.—THE VALLEY SLOPE.

That portion of the area which is to be described in the following section was a part of the Wet Mountain Valley depression before the Rosita Hills were formed by the succession of lavas poured out upon its eastern border. There is no evidence that the eruptives of the Rosita Hills ever descended the slopes of the valley in considerable masses, although rhyolite and the Rosita andesite covered the adjacent surface with a mantle of ashes and ejected materials, and the former may possibly have sent out some thin lava flows. From a vent on the slope at some distance from the volcanic center there was, however, an eruption of considerable magnitude, the product of which built up a small mountain. Since that time erosion has greatly reduced the prominence of the eruptive mass, the valley has been filled up to some extent, and to-day the rhyolitic elevations of Round Mountain and the White Hills are of quite subordinate importance. In describing the area, the smooth slopes covered by Pleistocene materials will be taken up first; then the Silver Cliff Plateau, formed of materials ejected during several eruptions; and lastly Round Mountain, representing the vent through which at least one of the important eruptions took place.

THE PLEISTOCENE AREA.

General description of the eastern valley slope.—The eastern slope of the Wet Mountain Valley about Silver Cliff is not so even as the opposite slope, nor does it reach so great an elevation before meeting the bordering hills. The chief reason for this inequality doubtless lies in the fact that the great Sangre de Cristo Range on the west rises much higher than the hills on the east, and has furnished in recent times a vastly greater amount of detritus to be brought down by its larger streams and spread out beyond their narrow canyon mouths in broad "alluvial cones" which unite and build up the valley slope in a marked manner. On the eastern side of the valley the action has been rather to carry away the wash accumulations of the slope than to build them up by débris from the hills.

From the view shown in Pl. XXVI one may get a good idea of the lower part of the valley slope, and in Pl. XXXI is seen the surface from the western base of the Rosita Hills to Silver Cliff. Pl. XXXVI also represents a portion of the Silver Cliff region.

Area south and southeast of Silver Cliff.—From the bottom land of Grape Creek up the regular slope south of the town there are no outcrops of solid rock in the belt near the southern boundary of the map until the rhyolite ridges west of Rattlesnake Hill are reached. The wash is presumably several hundred feet in thickness near the creek, but evidently thins out rapidly toward the hills (see Section BB of Pl. XXX), for along the road leading southeasterly from the town and passing to th southwest of Rattlesnake Hill there is a succession of small outcrops of gneiss extending from the second drain south of the town up to the hill adjoining the rhyolite. None of these outcrops is prominent, but the rock projects in little ribs or points above the wash of the ridges, or appears on the banks of the drains. It is noticeable here that the wash within a few feet of the gneiss is, as a rule, quite free from fragments of eruptive rocks.

The ridge south of the Rosita road is covered by wash, here containing many fragments of eruptives, and particularly of rhyolite. A number of prospect shafts have been sunk near the road, but only those near Silver Cliff have found rock in place, and there it is rhyolite, belonging to the mass south of Round Mountain. There is much rhyolite shown in the wash of the other shafts, and it is probable that the gneiss is covered by this eruptive at various points, if not continuously.

Slopes between the Rosita Hills and Round Mountain.—The Pleistocene of the ridges leading from Lookout Mountain westward is pierced by outcrops of gneiss and rhyolite in many places. The eruptive rock appears chiefly on the north bank of the drain next north of the Rosita road. With but three breaks, these outcrops extend from the slopes of the Rosita Hills to a point opposite Round Mountain, and form the only connection now existing between the eruptions of the two areas. This band of rhyolite is narrow and probably occupies what was a valley depression at the time of eruption, for immediately north of it the gneiss frequently appears on higher ground, and there are no further distinct outcrops of rhyolite on any of the flat ridges to the north. There are several small dikes of andesite which cut the rhyolite.

Beyond the Querida road the flat tops of the ridges have a heavy covering of wash, but in the ravines between them and in several knolls gneiss appears. Northward the Pleistocene grows less and less, and is restricted to the higher, smoother parts of the ridges. This country was described in the section on the area of gneiss and granite. Nearly all the eruptive rocks of the Rosita Hills are represented in the wash covering of these ridges much more abundantly than on the southwestern slopes.

The Pleistocene surface surrounding the rhyolite areas.—Round Mountain is completely surrounded by wash that is not deep enough to hide the general distribution of the underlying formations, though concealing the exact contacts and precluding a fully satisfactory knowledge of the old eruptive channel which is represented by the rhyolite mass. Toward the Blue Mountains there are very level spaces under which the wash is deep, and from the known outcrops it is probable that gneiss underlies it.

On the divide between the Blue Mountains and White Hills gneiss and rhyolite exposures meet, and to the westward, although the shallow drain between the two elevated areas is excavated in wash, there is so little of it that the relations of the formations are scarcely obscured. To the northwest of the White Hills the wash is deep only in the drain running westward, but the unevennesses of the underlying gneiss surface are all filled out, making very even slopes. On the southwest, however, the rhyolite disappears under a deposit of wash so deep that the limits of the eruptive rock have not been outlined by the prospect shafts, few of which have penetrated more than 50 feet. As far as the prospect shafts have found rock in place beneath the wash in this direction it has been rhyolite, excepting near the hills of gneiss west of the railroad.

Along the edges of the bottom lands the Pleistocene presents a little bluff from 25 to 50 feet in height.

ROUND MOUNTAIN AND VICINITY.

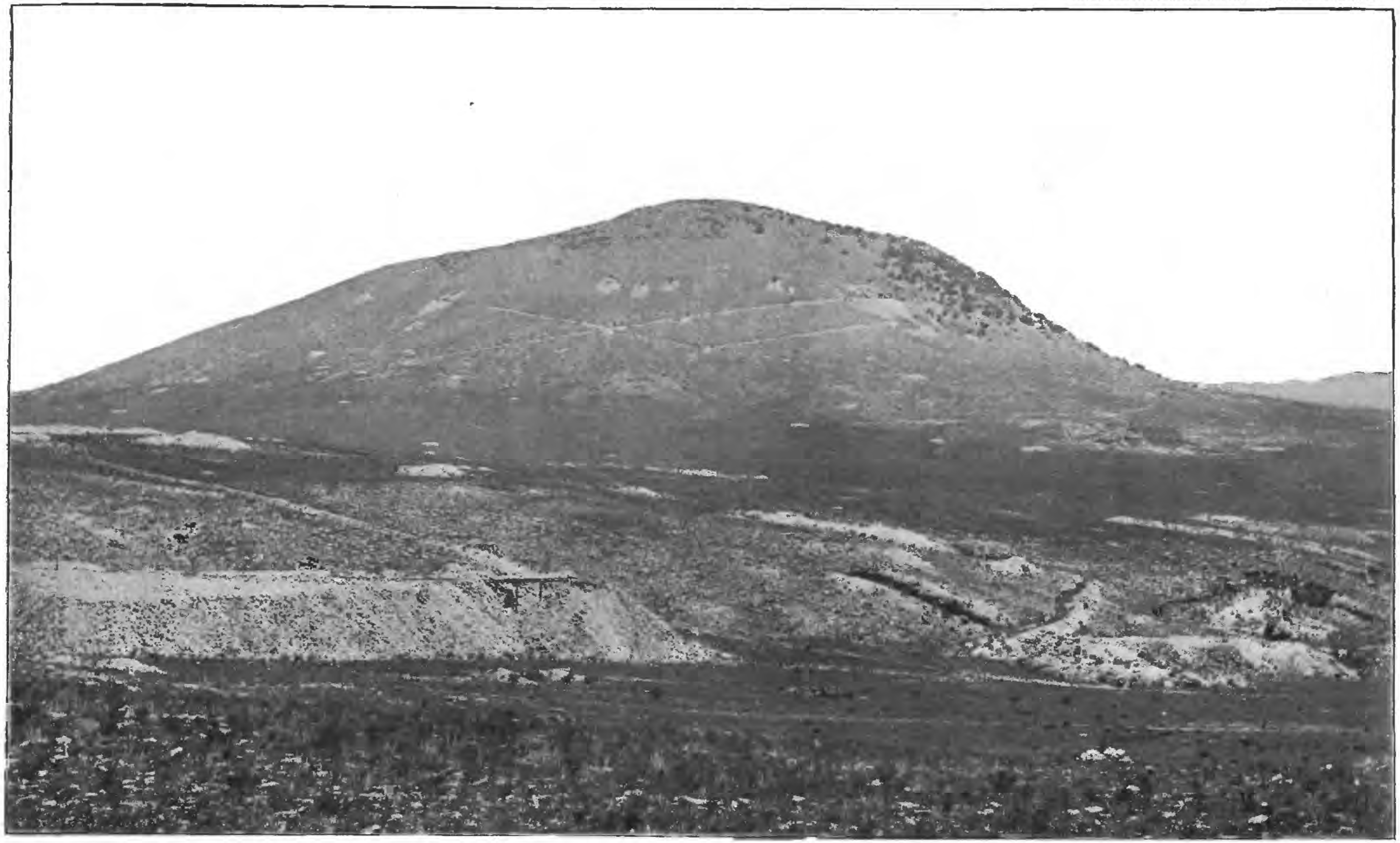
General description.—Less than a mile northeast of Silver Cliff is a hill 700 feet high, locally termed Round Mountain. It is really somewhat elongated in a north-and-south direction, with smooth, even slopes on the north and a more abrupt and irregular descent on the south. At the southern base the ground is uneven, but on all other sides the adjoining country is smooth and covered with Pleistocene gravels.

The view of the mountain reproduced in Pl. XXXVI is from the plateau by the Geyser shaft, looking a little north of east. The summit of the mountain is formed of dense, banded rhyolite, with a steep irregular dip to the structure. By weathering, it has broken into irregular blocks, many of them large, and these are strewn all over the slopes to the base of the mountain. On the south the rough, jagged cliffs, with straggling growth of stunted pines, are of breccia, of hard, flinty texture, the fragments being of banded rock and the cement highly siliceous. The slope below is covered with fragments of this breccia. Along a line slightly below the trees there are a number of exposures of a glassy form of the rhyolite, with imperfect perlitic cracks, and crumbling on exposure. The bare middle slopes of the mountain on this side are mostly covered by rhyolite slide rock, penetrated here and there by prospect tunnels disclosing rhyolite in place beneath. The lower, darker slopes are underlain by wash, for the most part a fine gravel, and very deep in many places. At the base of the mountain on the right hand one may distinguish in the plate the ruins of the Plate Verde mill, now largely removed, and the large white dumps on the slopes above indicate the "mines" which failed to supply the necessary amount of ore for the mill.

Details of geological structure.—It is of interest to know as much as possible of the structure of Round Mountain, in view of the fact that it apparently represents the vent from which the rhyolite masses of the Silver Cliff Plateau were poured out, and, as will be seen from their description, the eruptions were of considerable magnitude.

Practically the only data as to the exact form of the channel are obtained on the eastern slope, where gneiss runs high up and is cut off by the rhyolite on a contact which is shown in several tunnels and is closely indicated, as drawn, by outcrops and the admixture of gneiss in the slide rock below the line. This contact is nearly vertical or dips steeply westward. On the northeastern slope several tunnels starting in slide rock penetrate the gneiss for some distance before coming to the rhyolite. The contact is irregular and both rocks are much shattered and decomposed.

On the southern slope a narrow arm of gneiss, clearly connecting with the main mass to the east, curves around to the westward down a little gully, on both sides of which rhyolite is clearly in place. At the north end of the mountain no definite data are obtainable as to



VIEW OF ROUND MOUNTAIN, FROM NEAR THE GEYSER MINE, SILVER CLIFF.

the exact position and nature of the contact between rhyolite and gneiss. The main ridge seems to be composed of rhyolite down to about the 8,200-foot contour. Below that point slide rock from above and the Pleistocene wash cover everything deeply. On the western slope the superficial deposits completely hide the solid formations and have not been pierced by prospect holes, except near the outcrops of the ridge. On the southwest the relationships are likewise completely obscured.

THE SILVER CLIFF PLATEAU.

General description.—Between the town of Silver Cliff and the Blue Mountains is a low, rolling, plateau-like elevation which has been referred to in several places as one of the modifications of the valley slope due to eruptive masses. It is 2 miles long, north and south, and 1 mile wide, and the map gives a very accurate representation of its surface features. In the northern part is seen a series of little hills, called the White Hills from the color of the rhyolitic tuff composing them. Their highest point is 400 feet above the northern edge of the eruptive mass.

The Silver Cliff Plateau occupies the site of a former basin, in which there was a lake whose form and extent can not now be determined. At a period presumably contemporaneous with the rhyolite outbursts of the Rosita Hills a local eruption or series of eruptions of the same character took place at this point on the valley slope. The lake was filled and a hill of considerable magnitude was probably raised about it. Owing to the fragmental character of much of the material, and to the very general subsequent decomposition, this mass has been easily eroded and reduced to its present form.

The character of the southern part of the plateau is shown in Pl. XXVII, the reproduction of a photograph taken from near the Vanderbilt mine on the eastern edge, looking southward over the town of Silver Cliff. On the left hand the upper portion of the town is hidden by the cliff proper, above which appears the shaft house of the Geyser mine. On the right, one looks down one of the shallow drains and sees the merging of the plateau ridges with the valley slope.

There are few projecting outcrops of solid rock over the plateau, but, although there is a thin soil supporting a scanty vegetation, as seen in Pl. XXVII, the rock comes everywhere close to the surface. In the mining excitement of 1879 hundreds of trenches and shallow shafts were excavated in the smooth surface of the plateau, and few of them failed to show the rock in place. Mr. Eakins noted over 400 shafts 10 feet or more in depth in the plateau area proper, and there are probably twice as many more shallower ones. The view shown in the plate gives no adequate idea of the number of these prospects.

The most notable outcrop of solid rock is that on the southern edge of the plateau, where there formerly existed an abrupt cliff of blackened rhyolite from 30 to 50 feet in height. This was the marvelous Silver Cliff, in which masses of horn silver were found associated with manganese and iron oxides in fissures and cavities. The great quarries of the Racine Boy and Silver Cliff claims have eaten away the boldest parts of this outcrop, but have provided fine exposures in its place. Detailed descriptions of this locality and a view of the quarries will be found in the article by Mr. S. F. Emmons on the ore deposits of the region, which follows this paper.

In the higher parts of the White Hills, and here and there over the plateau surface, are some projecting outcrops, but the rock disclosed by the prospects is usually shattered through weathering. The smooth surface of several areas is underlain by black, fresh pitchstone, which makes a marked contrast to the white crumbling rhyolite. These outcrops are covered by the small angular particles into which the glass readily breaks, and there is seldom much soil over them. Owing to the wonderful local richness of peculiar ore deposits of the Silver Cliff, Racine Boy, and a few other mines, the entire area of the rhyolite plateau has been carefully explored, but to prospectors, mine superintendents, and many so-called experts the formation has been, in some particulars at least, a decided puzzle. The white earthy character of the prevalent rock has suggested the idea of hot-spring deposits, and the name "Geyser" has been chosen for the company at present owning the old Silver Cliff and other claims. In many places, as in the Vanderbilt, the rock is plainly fragmental and stratified, with a well-defined dip. The black pitchstone, or "obsidian," has been recognized as a volcanic product, but its relation to the other rocks has never been understood. Most puzzling of all have been the curious bowlders, in the irregular cavities of which ore has sometimes been found. These bowlders occur embedded in the pitchstone, or more frequently in a white clay, locally called "talc," which is a decomposition product of the pitchstone, as shown in the preceding chapter. The great beds of this pure "talc" encountered in some places have been difficult to understand, for its origin has apparently never been recognized.

The description of the area will begin with the evidence to be found in the Geyser shaft, where the thickness and relationship of the various materials of the formation are shown more definitely than in the surface exposures.

Data from the Geyser mine.—For nearly ten years the ground below the famous Silver Cliff has been explored almost continuously through a deep shaft begun by the Security Mining Company and continued by the Geyser Mining Company. From the outset this shaft and the explorations from it have been in charge of Mr. C. H. Johnson, to whom the Survey is under great obligations for the free and courteous manner in which he has granted facilities for the repeated examination of this interesting property.[1] The history and economic facts of this mine naturally belong to the discussion of the ore deposits of the region by Mr. Emmons, but most valuable information has also been obtained

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[1] This acknowledgment is also due to Messrs. J. J. Mitchell, E. W. Johnson, C. J. Haskell, and others connected with the Geyser Mining Company.

from the Geyser mine bearing upon the geology of the district, and of this a summary will be given in this place.

The Geyser shaft has reached at the time of writing (1896) a depth of somewhat more that 2,100 feet. At various depths levels have been run out from the shaft in search of ore bodies, and these workings have been examined by the writer at depths of 750, 1,850, and 2,000 feet, while the 2,100-foot level has been visited by Mr. Emmons. The facts of prime importance shown by these deep workings are: First, the demonstration that stratified rhyolitic tuff and breccia extend to the 2,100-foot level; and second, the general character of the formation to this level has been ascertained.

The shaft starts at the point indicated on the map, and shown in Pl. XXVII, in massive banded rhyolite. According to Mr. C. H. Johnson, the rhyolite continued to a depth of about 150 feet, and was succeeded by a zone, nearly 50 feet in thickness, characterized by large spherulites, below which came about 67 feet of pitchstone, and then the shaft passed into fragmental rocks, tuff or breccia. The massive rhyolite, the spherulitic zone, and the pitchstone evidently belong to the flow whose surface development and relations are to be described. The pitchstone was much decomposed in the spaces between spherulites, but was fresh in some places below.

A detailed section of the stratified tuffs can not be given, but a general statement is in this case sufficiently accurate. From the top to the bottom the material has varied much in texture and in the quantity of gneiss and granite fragments contained in it. The greater part of the rock is to be described as tuff—a soft, white, crumbling, distinctly fragmental material, sometimes finely stratified, and again occurring in beds a hundred feet or more in thickness within which structural planes could scarcely be distinguished. No other volcanic rock than rhyolite has been recognized, but the thoroughly kaolinized condition of most of the fragments renders it impossible to make a positive statement that no other types occur.

Small particles of quartz, feldspar, or dark silicates, derived from the gneisses or granites of the region, are to be found in nearly all of the tuffs, and fragments of these rocks, reaching 2 or 3 feet in diameter at a few places, are found abundantly in various parts of the section. The quantity has sometimes increased so much as to cause the belief that the bottom of the tuff series could not be far away, yet below such material fine-grained tuffs of predominant rhyolite have again been encountered. Occasionally the fragmental rock is so composed of angular fragments that the term breccia best characterizes it.

A significant constituent of the tuffs, found at various levels, is charcoal or lignite. This occurs as far down as the 2,000-foot level, according to Mr. C. H. Johnson, and several specimens have been obtained by the writer. Pieces as much as 2 feet in length are said to have been found.

The bedding of the tuffs is sometimes nearly horizontal, but a northwesterly dip of 10° to 15° is not uncommon in the upper part of the working. In some places much steeper dips may locally appear, but they seem connected with the fault fissures which traverse the tuffs on all levels, and can not be taken as indicating general dips.

Surface water was encountered in the upper workings, especially at about 340, 390, and 420 feet from the surface. The quantity of water at these horizons has decreased with time, and all indications are that the shaft has drained a basin in which water had accumulated. In the workings below 1,000 feet there is but little water referable to immediate surface sources. The extremely interesting water courses of different character met with in the lower levels are especially treated by Mr. Emmons. In these the water is heavily charged with carbonic acid, and contains much mineral matter in solution, and as the acid gas escapes in the drifts a deposit of calcareous sinter rapidly accumulates.

Shortly before reaching the 1,850-foot level the vertical shaft passed into gneiss and granite, the latter as intrusive bodies in the former, and has continued in these rocks to the bottom. Drifts south and east from the shaft at 2,000 and 1,850 feet show the gneiss and granite, massive in places but much brecciated in certain zones. The levels west and northwest from the shaft pass out of gneiss into rhyolitic tuff or breccia of the massive variety known above. The contact between gneiss and tuff seems to be a fault plane or fissure zone dipping northwesterly, but there has been so much fracturing and dislocation, and the fissures are so characterized by the waters charged with gas and mineral matter, that a clear understanding of the relationships between gneiss and tuff has not yet been reached. It does appear beyond question that the greatest depths of the rhyolitic formation have not yet been reached in the territory west and northwest of the shaft.

Reviewing these facts, it appears certain that a deep lake-bed deposit of rhyolitic tuff exists under a part of the Silver Cliff Plateau. By a reference to the geological map and to the profile sections of Pl. XXX, it is clear that the lake must have been very circumscribed on all sides except on the west. The profile of Section CC is drawn on the assumption that the tuffs penetrated in the Geyser shaft were deposited in a narrow deep arm of a lake whose principal extent was in the valley to the westward. The stratified nature of the tuffs does not permit an hypothesis that a vent is situated at this point.

Relations of rhyolite tuff and gneiss.—The line of the contact between rhyolite tuff and gneiss is well defined from the divide west of the White Hills around to their northeastern base. The boundary line is seldom visible in actual outcrops, but the Pleistocene covering is so thin that, thanks to the numerous prospect holes dotting the surface, the limits of the tuff can be plainly determined.

There is no question that the fragmental rhyolite material of this border rests upon a gently undulating surface of gneiss. As shown by the map, the tuff appears on the ridges, while the gneiss approaches the White Hills in the beds of the shallow drains. On nearly all of the little ridges there are prospect shafts starting in tuff and passing into gneiss at about the level of the contacts seen in the drains.

Along the western border of the tuff the underlying gneiss is found in most prospects to be much broken and now resembling breccia. Whether this is simply surface débris of the prerhyolitic period or represents material broken up by explosive action attending the outburst of the rhyolite can not be clearly made out. As gneissic fragments appear at intervals all through the brecciated part of the rhyolitic formation, the latter explanation seems plausible.

At the Songbird and Mountain View [1] mines, and, in fact, along the greater part of the northern border zone, the gneiss under the rhyolite tuff has been much altered and is locally changed into quite pure iron ores, which are sometimes magnetite and in other places pyrite. In the Immortal and Keystone claims the pyrite is mainly in veins, but the gneiss is impregnated with the same mineral or its alteration products over a considerable space.

The relations of gneiss and tuff are most clearly shown in the drain between the Keystone and the Sunrise claims, where the contact line is clearly seen. In the bed of the drain is a dike of unique character, a fine-grained quartz-porphyry, with groundmass largely of quartz and orthoclase in micrographic intergrowth. It probably belongs to the same general period as the syenite dikes, and has the syenite color on the map. The Sunrise shaft had been abandoned at time of visit, but it was found to be more than 100 feet deep. The surface of the dump shows only rhyolitic matter, a fact probably due to drifting in upper levels after the shaft had penetrated gneiss. The near approach of the gneiss on the west, and the fact that several prospects on the slopes east of the Sunrise found gneiss within 30 feet, make it highly improbable that any considerable thickness of rhyolite tuff can be present at this point.

The relations of tuff or massive rhyolite to gneiss in all the southern portion of the mass are entirely obscured by surface deposits. There is no ground to suppose that there is any intervening rock at any point, however, and the small exposures of gneiss adjoining Silver Cliff on the southeast indicate the limit in this direction. Gneiss appears on the eastern slopes of Round Mountain, and it is only in the direction of Grape Creek that there can be any considerable extension of the rhyolite formation under the valley alluvium.

The area of fragmental rhyolite.—All of the northern half of the Silver Cliff Plateau region is made up of breccia and tuff, except a few later dikes of massive rock. The material is now much kaolinized and locally iron stained. Its fragments are seldom more than a few inches in diameter, and some layers are fine-grained tuffs. There is a distinct bedding seen in many places, and a rapid alternation of fine and coarse materials. In general the mass seems to have been arranged in water, and from the evidence of the Geyser shaft the conclusion is natural that the tuffs of the present surface are simply the upper deposits in the lake known to have existed at this point.

In the area near the Sunrise shaft and along the eastern border of the mass as far south as the Vanderbilt claim there is a great deal of fine, evenly bedded tuff, with southerly or westerly dips, varying from 0° to 20°. In the higher points of the White Hills the rock is less frequently well stratified and the bedding is roughly horizontal.

The thickness of fragmental matter below the highest point of the hills is more than 330 feet, for a shaft on the southern slope, starting at 190 feet below the summit, penetrates rhyolite for 140 feet without reaching gneiss. But the course of the line between gneiss and tuff north and east of the hills indicates no great depth for the former lake at this place.

These fragmental beds seem to end on the present surface approximately on a line running nearly east and west and situated just south of the Vanderbilt. Exposures are not sufficiently distinct to show the exact nature of this limit, but the writer is inclined to believe that it indicates a fault, with a probable displacement of less than 100 feet, by which the area on the south has been lowered, and thus pitchstone or massive rhyolite above it has come in contact with the breccias and tuffs north of the fault.

The main argument in favor of a fault is found in the relationships exhibited near the Vanderbilt prospect cut. In this excavation are very distinctly stratified tuffs dipping south about 20°, while not many yards to the south pitchstone forms a considerable outcrop in the depression at this point, and beyond this the pitchstone, or the massive rhyolite above it, occupies the entire surface. The tuffs of the Vanderbilt thus apparently dip directly against the pitchstone. It is of course possible that the lava flow to which the pitchstone and massive rhyolite belong is situated in a depression eroded out of the earlier fragmental rock, but there is no special evidence of such erosion.

The pitchstone area.—It was shown in the Geyser shaft that the position of the pitchstone was between the tuff beds and the massive banded rhyolite above, and this relation holds good for the entire area of the plateau. The greater part of the pitchstone outcrops occur in two depressions on the eastern side of the plateau, with a narrow connecting band between them. Isolated exposures occur in the beds of drains farther west. As the pitchstone merely represents a portion of the lava flow which cooled quickly, as glass, it is clear that its development must have been very irregular and determined by local conditions of the time of eruption.

The largest patch of the pitchstone is exposed in the little depression south of the Vanderbilt mine, at the head of the drain running southwest, which is shown in Pl. XXVII. Here the surface is formed of a black, variegated, yellowish, reddish, or greenish glass, which, though breaking up into small flakes or sherds, is quite fresh and glistening, and is not much covered by soil.

On the north, west, and south the pitchstone is bounded by white banded rhyolite, with a spherulitic zone of variable importance between them, to which reference will be made below. As stated above, the banded rock soon comes into contact with the fragmental beds on the north, along a line whose character is not clearly shown. Eastward the Pleistocene wash covers the border of the pitchstone, and the rhyolite shown by deep prospect holes seems to be fragmental, with a dip southwesterly, carrying it under the pitchstone.

A narrow band of pitchstone running along the eastern edge of the plateau connects this northern area with the one to the south. Between this glassy band and the rhyolite on the west the usual spherulitic zone appears, and some shafts near the line pass into pitchstone below the rhyolite, while on the east there is a sufficient exposure of tuff and breccia to show the succession. Between the Racine Boy and the Boulder-Buffalo claims the pitchstone outcrop expands in the depression in the foreground of Pl. XXXVI, owing to erosion, and passing over a little divide, appears in the drain north of the King of the Valley shaft [3].

It is fresh and black in the western portion of this area, but has been much altered near the Boulder-Buffalo claims. The spherulitic zone is here developed in great prominence, and will be described in detail in a subsequent section of this chapter.

Were the alluvial materials of the gulch removed, the pitchstone would be found to outcrop between the cliff and the town of Silver Cliff, for the glassy rock was exposed in grading the street opposite the Geyser quarry. Spherulites in clay, resulting from the decomposition of the glass, appear on the north side of Chloride Gulch, in the Fleetwood tunnel, and glassy rock was found in a drill hole on the Belfast claim. It is not improbable that the pitchstone occurs under the alluvium along the south bank of the gulch as far at least as the line of the town of West Cliff, for it has been struck in a shallow prospect hole in the western part of Silver Cliff.

Several isolated outcrops of pitchstone appear in the drain beds west of the main area, at the points shown by the map. No doubt the glassy portion of the lava flow is here thicker than usual, and hence is exposed by erosion.

From the known data it is plain that the pitchstone of this area holds a definite position as the lower part of the lava flow to which the surface rhyolite of the southern half of the Silver Cliff Plateau belongs. It is not known that it is everywhere developed, and its presence beneath the rhyolite north of West Cliff is only to be inferred by analogy. If the present inclination of the basin to the southwest and the source of the flow as in Round Mountain vent be assumed, it is quite probable that at the parts farthest removed from the source the rock should be more crystalline, and thus glassy forms would be less prominent if not entirely lacking to the westward. Prospects sunk in spherulitic material near the road leading along the western edge of the plateau have shown pitchstone in but a single case, as far as observed. In a 10-foot hole west of the Wildcat [5] Mr. Eakins reports pitchstone at the bottom.

The area of massive rhyolite.—In distinction to the rhyolitic tuffs of the northern part of the region, the rock occurring above the pitchstone is massive in the sense that it belongs to an effusion crystallizing in its present position, and is brecciated only along lines of subsequent fracture. The typical development of the rock is that so well displayed in the quarries near Silver Cliff and in the new cut on the Boulder claim, as described in Chapter II. The marked feature of most of the rock is a banding or fluidal structure, which is to be taken as indicating by its dips and variations the character of the surface upon which the molten lava was poured out. A corresponding structure, as brought out by trains of microlites, is observed in the pitchstone.

In the Racine Boy and the Geyser quarries, and in the Boulder cut, the dip is seen to be northerly, at angles not far from 15°, and it is much more regular for some layers or bands than for others, indicating different consistency in different effusions.

As shown by the prospect holes scattered over the plateau, the rock is often much kaolinized, but many holes merely penetrate the surface débris to the underlying rock, so that they afford little evidence concerning the latter.

In the lower parts of the massive rocks there are sometimes cavities and lithophysal pores lined by quartz crystals, and topaz and garnet are present occasionally, as seen in the rock of the Geyser quarry and in a little outcrop on the north side of Chloride Gulch, below the Silver Cliff mill. These cavities are, as was shown in describing the rock, merely a phase of the spherulitic formation, and occur in the zone between the spherulites and the more compact, banded rock.

Crossing the Geyser and Racine Boy claims is a vertical band of fine brecciated rock running about east and west, and other lines of similar fracture are visible in many places. These give, under many conditions of exposure, the appearance of belonging to breccias which one might readily suppose to be of the same nature as the breccias of the northern part of the field. When these breccias occur above the pitchstone, however, they can be confidently assigned to the massive rhyolite horizon, especially if there is no variation in character of the rock represented in the fragments.

The "bowlder" zone.—One of the most puzzling phenomena of this region to those engaged in mining has been the zone of large, rounded, concretionary masses found in many places, and occasionally carrying ore in cavities, as at the old Boulder quarry. In Chapter II the true character of these bodies has been explained. They are very dense aggregates of fine feldspar needles radiating from near the center of each spherulite, and were formed as the rock solidified. There is some silica, as quartz or chalcedony, between the needles, and the spherulite in its fresh state has the average rock composition and is one of the forms in which the material may solidify. The position of the spherulites is between the pitchstone and the banded rhyolite, the lowest of the bands being surrounded by the glass, while in the upper part the interspherulitic material is more or less microcrystalline and grades insensibly into the banded rhyolite.

The character and position of these bodies are perhaps most plainly shown in the long cut on the Boulder claim, of which a view is given in Pl. XXVIII. The cut starts on about the line of pitchstone and rhyolite, and for 100 feet or more the walls show huge spherulites, some of them 6 feet in diameter, lying in a white clay easily seen to be a decomposition product of pitchstone, remnants of which appear in it, while in places there are considerable masses of glass yet remaining. As the flow has here a generally northerly dip, the cut gradually passes into the zone where the felsitic rhyolite replaces glass between the spheres, and then still farther into finely banded rhyolite above. In this cut the relationship between pitchstone, spherulites, and rhyolite, and the origin of the white clay from the glassy rock, are more clearly exhibited than in any other place known to the writer.

Just a few yards east from this cut is an older opening on the Boulder claim where the same relation of glass and spherulites is seen. But here secondary alteration has changed the spherulites more and obscured their character somewhat. Quartz, chalcedony, and opal may be seen in irregular cavities in the spherulites, and some chloride ore has been found in them at times, as also psilomelane and ocher, showing that the characteristic ore minerals of the region were deposited in the spherulites as in other parts of the rhyolite, when they were fractured.

The two places mentioned occur on the line of pitchstone outcrop, and the same curious bodies may be found in some development all along the upper contact of the pitchstone. As the glass is frequently decomposed to the white clay, which is easily carried away, the spherulites or fragments are found lying loose on the surface, or, if shown in shafts which start in rhyolite above, they are embedded in clay, and the complex resembles a conglomerate, as it is often called by prospectors.

As stated above, the spherulites characterized a zone 50 feet thick in the Geyser shaft, a development not commonly found. They were also encountered in the drifts of the King of the Valley mine, and are shown in many prospects above the pitchstone over the southern half of the rhyolite plateau. Their distribution over the southwestern slopes, near the border of the rhyolite outcrops, is indication of a considerable extent of this flow under the Pleistocene of the valley.

THE MINES OF CUSTER COUNTY, COLORADO.

BY

SAMUEL FRANKLIN EMMONS.

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THE MINES OF CUSTER COUNTY, COLORADO.

By S. F. Emmons.

INTRODUCTION.

After the completion of the field work for the monograph on the Geology and Mining Industry of Leadville by the members of the Rocky Mountain division of mining geology, then under my charge, it was decided that the most promising field for similar work, considering the limited amount of Survey funds that could be allotted to economic geology, was in the Rosita Hills of Custer County and among the new and extraordinary deposits near by in the White Hills of Silver Cliff. A topographical survey was accordingly made of the region during the summer of 1882, and in 1883 the areal geology was completed by Messrs. Cross and Eakins. Such of the mines as were open at that time were examined, but the blight which is so apt to attack new mining districts had commenced to have its effect upon the mining industry of this region, and already many of the mines were temporarily or permanently closed. As it is impossible to properly study the ore deposits of a region unless access to them may be had through a considerable extent of deep-mine workings, it was judged best to postpone the publication of the results already obtained with regard to the general geological structure until, with a resumption of interest in this undoubtedly rich district, a sufficient number of important mine workings could be studied in detail to afford material for a treatise on its economic geology, this being the primary object for which the work was undertaken. Since the completion of field work, visits have been made to the region by Mr. Cross or myself in 1887, 1888, 1890, 1894, and again in 1895, whenever there seemed to be a chance of gaining access to one or more of the larger mines, but as yet we have not succeeded in making a thorough examination of any one mine. It having been decided, however, that Mr. Cross should publish his areal geology of the region in the present volume, I have judged it best to add the accompanying descriptions of such mines or parts of mines as have been examined, as a supplement to his report, adding the few deductions that I have been able to make, in the hope that even in their incomplete and imperfect condition they may prove of interest to the mining geologist and be of some practical use to the miner.

CHAPTER I.

ROSITA AND SILVER CLIFF DISTRICTS.

HISTORICAL.

The broad, well-watered bottom lands of the Wet Mountain Valley, lying along the eastern front of the stately Sangre de Cristo mountain range, were early settled by an agricultural population before it was discovered that the neighboring hills contained any considerable store of mineral wealth. It is said that the first permanent occupation of this valley was made by a colony of German immigrants.

The well-rounded and grass-covered slopes and valleys of the Sierra Mojada, or Wet Mountains, to the eastward, were the favorite pasture grounds for the cattle of the ranchmen in the valley, and the first specimens of ore were picked up there as curiosities by herdsmen wandering over the hills in search of stray cattle. The value of the ore thus found was first recognized by Alex. Thornton, then engaged in opening up coal banks south of Canyon City and iron deposits on Grape Creek for the Denver and Rio Grande Railway Company. Prospectors were attracted to the region in the autumn of 1872, and Mr. Thornton came himself in the following summer and remained in charge of various mining operations, notably of the development of the Humboldt-Pocahontas vein, more or less continuously for about fifteen years.

The mine first discovered in the region was the Senator (since rechristened the Maverick), which was located in the autumn of 1872 on an outcrop of cavernous quartz, with galena and silver glance in the cavities, which was extremely rich. After it had been opened to a depth of 50 to 60 feet, however, the ore seemed to pinch out and the mine was for the time abandoned.

In April, 1874, a thin seam containing carbonates of copper, with native silver, was discovered on the southern slopes of the hills back of Rosita. This was the outcrop of the since famous Humboldt-Pocahontas vein, which runs northwest and southeast. On this were located first the Humboldt, then the Pocahontas, and later the Virginia and East Leviathan claims, as extensions to the southeast and northwest, respectively. The Humboldt-Pocahontas mine has been the most permanent and steady producer of any in the region, and was worked more or less continuously for nearly fifteen years, producing, according to census reports, over $900,000 worth of ore.

The hills around were rapidly honeycombed by the excavations of prospectors, and a picturesque mining town, known as Rosita, soon sprang up and reached the height of its prosperity, with a population of 1,200 to 1,500 inhabitants, in the years 1875–1877. Many small bodies of extremely rich ore were discovered in the neighboring hills, but few were developed to a sufficient depth to be worthy of the name of mines.

The next great mine was discovered about two miles north of Rosita, in 1877, by E. G. Bassick, a sailor turned prospector, who had had varied experiences in many parts of the world. He first named the prospect the Maine, from his native State, and, as the story goes, being too poor to develop it himself, he walked all the way to Pueblo carrying some of the ore in his kit to have it assayed. It proved so very rich that he found no difficulty in raising capital for its development, and around the mine soon sprang up the little town of Querida. It is said that ore worth $500,000 in gold and silver was taken out of the mine in the first year and a half, and that in 1879 he sold it to Eastern capitalists, receiving half a million dollars in cash and a tenth interest in the stock of the new company. This company, with a nominal capital of $10,000,000, is said to have produced over a million and a half in gold and silver, of which $425,000 was paid in dividends to the stockholders. There seems, nevertheless, to have been something wrong in the management, and it was finally closed down in 1885, when its shaft had reached a depth of 1,400 feet, although, according to miners who were working in the mine at the time, the ore body appeared as large and as rich as ever. Since that time it has been sold several times at sheriff's sale to satisfy judgments obtained against it, and there has been much litigation in regard to its ownership, which is apparently not yet settled, since it has not been reopened.

When the Rosita Hills had been pretty thoroughly prospected attention was directed to a lower outlying group of hills which rise out of the gently sloping plains on the immediate border of the bottom lands of the Wet Mountain Valley. In 1878 three lumbermen—Edwards, Hafford, and Powell—who were engaged in hauling timber from the Sangre de Cristo range to Rosita, had their curiosity aroused by the black cliffs that stood out so prominently on the southern end of the White Hills, which they passed in going to and from their work. One day they climbed over the cliffs and gathered several pieces of a dark, greasy-looking mineral (horn silver), which, when heated in the stove, melted into a metal resembling silver. When some of these pieces had been sent to an assayer and it was learned that the mineral, when pure, contained 75 per cent of silver another "boom" or mining excitement ensued. The discoverers promptly located the Racine Boy, Silver Cliff, and other claims, the surface of the ground in this portion of the valley was soon pitted with prospect holes, and a third town grew rapidly up, named from the mine, Silver Cliff.

In the Blue Mountains, an isolated group of hills about 2 miles north of this town, the discovery was soon after made of the remarkable deposit which later became widely known as the Bull-Domingo mine, from the two claims of which it was the consolidation.

About this time the excitement about the wonderful bodies of silver ore discovered at Leadville was at its height. Its effect upon this region was a double one. It drew away from Rosita many of the miners and prospectors who, not having money enough to develop their claims, thought in the new region to discover others in which Eastern capital might be more ready to embark; it thus marked the commencement of the decadence of this town. On the other hand, the mining boom gave a great impetus to the development of mines throughout Colorado. Accounts of sudden wealth acquired by individuals, which were more or less embellished en route, reached the East at a time of great commercial prosperity, when much unemployed capital was seeking investment. There ensued not only a demand for mining investments, but, attracted by the stories of sudden and readily acquired wealth, many men with little or no experience in mining came West and personally engaged in the development of mines. A portion of this surplus capital found its way to the Silver Cliff region, and together with it, to judge from the results, no small number of inexperienced miners.

The Silver Cliff and Bull-Domingo mines were early sold to Eastern capitalists; stock companies were formed with a capital of $10,000,000 in each case, and the stock was listed on the New York Stock Exchange, but, so far as known, no dividends were ever paid on the stock of either mine.

About this time a branch of the Denver and Rio Grande Railroad (narrow gauge) system reached the district, leaving the main line at the mouth of the Royal Gorge of the Arkansas River and ascending the narrow winding valley of Grape Creek, through which the drainage of the greater part of the Wet Mountain Valley finds its outlet. For a short times after the advent of the railroad there was an apparent increase of prosperity in the district, resulting from the necessary reduction in outward freight for ores and in the cost of supplies brought in. A new town called West Cliff was started around the railroad station, which apparently had been located about a mile away from the town of Silver Cliff for the purpose of affording an opportunity of selling town lots. But the reaction that almost necessarily follows every great mining boom had already set in, and unnatural discouragement had succeeded to exaggerated hopes; the aggregate population of the two towns soon became less than that of the one previously existing, though it was now scattered over double the area formerly occupied. The railroad, moreover, had been badly located. The gorge of Grape Creek over an extent of many miles was so narrow that the track had to follow its very bottom for a great part of the distance, and was submerged at every freshet.

It was found that Wet Mountain Valley was not so named without good reason. During the showery season of early summer in each successive year there came some unusual powerful rainstorm, such as is appropriately known in the West as a "cloud-burst," when for a short time the rains descended in torrents all over the broad valley and the surrounding mountains; and when all this water, gathered together from a surface area over 20 miles in diameter, was suddenly emptied into this narrow outlet, it poured down the narrow gorge with a force that nothing could withstand. Culverts and ballast were washed away and long stretches of track lifted bodily up and carried downstream, the iron rails being twisted up as if they were as flexible as ropes; so that every year many miles of track had to be entirely relaid, and just at the season when business was most pressing. With decreasing business and constantly increasing cost of maintenance of way it was inevitable that there should come a time when the railroad company would feel obliged to abandon the line, and this occurred in 1888, when after one of these storms, instead of replacing the rails that had been torn up, they simply took up those that were left.

It were unjust to ascribe the decadence of the district entirely to the failure of its mines or to a want of permanence in its ore bodies, for while the value of many of them was doubtless exaggerated during the mining boom, the ore bodies that have been persistently and systematically worked afford good grounds for the belief that under a similar intelligent development many other bodies would have afforded as good or even better results.

No inconsiderable part of the failures that have cast a cloud over the district are to be ascribed to causes that are entirely independent of its natural mineral resources or their mode of occurrence. In too many cases they have arisen from ignorance of or want of experience in the underlying principles of mining and smelting. Moreover, when the mining excitement was at its height, so prevalent and general was the belief in the marvelous and exceptional character of the ore deposits that the camp was a most promising place for the introduction of patent processes which, disregarding the rules of chemistry and metallurgy, would furnish a short road to wealth in treating ores that were supposed to have been formed in opposition to all known laws of geology. A complete history of the many different plants that have been erected in this region and of the causes that have led to the failure or abandonment of the greater part of them would prove a very instructive object lesson for future developers of new mining districts, and might doubtless afford a useful warning to those who may undertake to reopen some of the many promising mines of this district. Unfortunately it is no longer possible to obtain complete or authentic records with regard to the many different reduction plants that have been erected first and last in this region, and still more impossible to learn the actual causes of their abandonment.

At my request Mr. Sherman G. Sackett, a well-known mining engineer and metallurgist, who was for several years superintendent of one of these reduction plants, gathered from various sources the best available information, either from records or from recollections of the inhabitants or of persons at any time connected with the different works. The following succinct statement of the essential facts thus obtained may prove instructive, even though it is not complete, either as to the number of plants or as to all the facts connected with either of them.

REDUCTION PLANTS.

The James Cupola Furnace, built at Rosita in 1875, appears to have been the first reduction plant for smelting the ores of the district. It was such a furnace as is used in foundries for remelting iron, and, after a few attempts to reduce ores containing sulphides and arsenides of silver with no considerable amount of lead, was closed down.

The Rosita Reduction Works were erected at Rosita in the same year to treat ores from the Pocahontas mine by chlorination, roasting, and pan amalgamation. It consisted of a crusher, a ball pulverizer, a roasting furnace (with hearth 40 by 9 feet) for chloridizing, two Varney pans, and one settler. To this were afterwards added lixiviating vats. It cost $31,000, and was run for three or four months, and closed down because of high costs and losses by volatilization. In 1879 it was sold for $4,000 to a new company, which changed it to a lixiviation plant for the Patera process, and after running at intervals from June to September, 1879, it was again closed down. A new company took possession of the works in 1880 and made further attempts at lixiviation on the ores of the district, but was soon discouraged, and no work was again attempted.

The Mallet Lixiviation Works were erected near Rosita in 1876 for a secret process supposed to be analogous to the Augustine method of leaching silver-bearing ores. At that time ores containing less than 50 ounces of silver to the ton could not be shipped out of the district, and were purchased very cheaply for these works, which are supposed to have been profitably worked from December, 1876, to October, 1877. They were afterwards moved to Canyon City, where they were not successful.

The Pennsylvania Reduction Works were built at Rosita in 1877 to treat ores from the Humboldt and Virginia mines. They consisted of a crusher, 5 to 10 stamps, 2 Brückner cylinders for roasting, and pans and settlers for amalgamation. In the first ten months' run 1,204 tons, containing 47,418 ounces of silver, were treated, and 31,303 ounces of silver, or 63.44 per cent, were saved, at a cost of treatment per ton of $17.84. This cost was later reduced to $11 by an increase in the stamping capacity. The works were closed in 1878 by reason of the exodus to Leadville, and were never started up again; they were burned in 1883.

This record shows considerable enterprise on the part of the mine owners of Rosita, and the failures are hardly to be wondered at, considering that at that time very little was known in Colorado about the treatment of silver ores, and costs were necessarily very high at Rosita during all this period.

The St. Joseph's Smelter was erected in 1879 on Grape Creek, near Silver Cliff, to treat copper ore coming from the Sangre de Cristo Mountains. It was clumsily built, had 5 stamps with square wooden stems, a calcining furnace, a matting furnace, and a kiln for roasting. It was erected by a Catholic priest, but the funds, which were raised by subscription, gave out before it was completed, and the furnace was never run.

The Chambers Smelting Furnace was erected in the same year at Gore Station, near Silver Cliff, being designed to treat the ores of the Bull-Domingo and other mines. It was well constructed, being made by Fraser and Chalmers, and had a Blake crusher, Cornish rolls, 2 reverberatory furnaces (50 and 55 feet long, respectively) for roasting, 1 circular water-jacket blast furnace with a Root blower, with a nominal capacity of 20 tons per twenty-four hours. These works were in operation intermittently for eighteen months and then closed down.

The Waitz Mill, erected in 1880 in Silver Cliff, contained a patent roasting furnace, a long reverberatory with a series of step hearths designed to roast without access of air, and a patent amalgamator consisting of 2 iron cylinders through which the material to be amalgamated was forced by screws. A number of experiments were made on ores in the vicinity and the mill was then closed down.

The Adelia Mill, finished in 1880 at what was later known as West Cliff, was a wet-crushing mill for amalgamating free-milling ores, and was designed for custom work. It had a rotary crusher, 20 stamps with settling boxes for the pulp, amalgamating pans, and settlers. It was found that the mixed ores of the district would not amalgamate, though a successful run was made on a lot of ore from the Racine Boy mine. In 1883 the Kate Mining Company came into possession of the mill and tested their ore, which was similar to that from the Racine Boy, after which it was finally closed down.

The Boulder and Buffalo-Hunter Mill was erected in 1880 near the Adelia to treat ores from the mines of the same name. The plant consisted of a Holmes patent grinder (for reducing to go through 80 mesh screen), a set of Waitz patent roasting furnaces, and a pair of Waitz patent amalgamators, and had a nominal capacity of 10 tons per twenty-four hours. The cost of the plant was $15,000. It ran two days, crushing 9 tons, wore out the grinder, and the rest of the process being unsatisfactory it was closed down.

The Silver Cliff Smelter, a 15-ton water-jacket blast furnace, was erected on Grape Creek 3 miles north of Silver Cliff in 1880, and was closed down after "freezing" several times in unsuccessful runs. It was burned in 1883.

The Robbins and Dyer Mill was erected in Silver Cliff in 1880. It contained a crusher and rolls, 2 Holmes patent grinders of different patterns, and an arrastra. The mill was in operation as a sampling mill at intervals during the summers of 1880 and 1881, and later closed down.

The Duryee Furnace, erected in Silver Cliff in 1880, was a rotary iron cylinder, 4 feet in diameter and 30 feet long, lined with fire brick and inclined at an angle of 2°, designed to use petroleum as fuel and to accomplish an exhaustive smelting in one operation, the precious metals being collected in the fumes. The ore was charged at the upper end, and the molten matter flowed out at the lower end into a sump or crucible. Back of this was the bridge, over which the flames produced by the combustion of gas mixed with heated air entered the cylinder. The fumes were conducted through a long series of dust chambers. Over $150,000 was expended during three years in unsuccessful experiments with this furnace, among which were the lengthening of it to 70 feet, the introduction of gas as fuel, and a spray water jacket, but as far as known there was no successful smelting of ores accomplished.

The Plate Verde Mill, erected in 1881, was placed immediately below the opening of the Plate Verde mine, on Round Mountain, a mile northeast of Silver Cliff. This was a well-constructed 40-stamp wet-crushing mill, with crusher, automatic feed, 16 amalgamating pans, and 8 settlers, with large settling tanks for tailings outside the mill; it cost complete about $175,000. A very successful device was introduced by the superintendent during the runs for reducing the amount of floating dust in the mill. Two runs were made on such ore as was available from the mine. The assay value of the first lot of ore is said to have been 5 ounces of silver to the ton and of the second 3 ounces, after which the mill was closed down, and in the autumn of 1883 it was sold and carried away.

Silver Cliff mills.—The first mill for treating the ores of the Racine Boy and Silver Cliff mines was started in January, 1880. It was a 40-stamp dry-crushing mill, provided with crusher, pans, and settlers, and was built by Morey & Sperry. It had a nominal capacity of 60 to 80 tons, but as the ore was somewhat moist its practical capacity was found to be but 40 to 50 tons per twenty-four hours. It is said to have treated about 10,000 tons of ore during the year 1880, of which 6,000 tons had an average of 35 ounces of silver per ton and were reduced at a profit. Later the silver contents of the ore became reduced, and after a test of 500 tons in the Adelia mill it was decided to build a new mill.

The second mill, erected near the first and within reach of the mines, was a very substantially built Fraser and Chalmers 40-stamp wet-crushing mill, calculated to treat twice as much ore as the dry mill. It had two 80-ton Blake crushers and the usual complement of settling tanks, pans, and settlers. It ran during the season of 1882, and is said to have crushed about 30,000 tons of ore, at the rate of 130 tons per day. Although the cost of working was thus greatly reduced, the grade of the ore decreased at a still more rapid rate. The mill was closed at the end of the year, and has not since been reopened. From the assay records for November, 1882, it appears that at that time the average value of the ore treated was 7.5 ounces of silver, and that the tailings contained 5.2 ounces per ton.

The tailings were not collected, but were allowed to flow down the shallow ravine. They thus furnished a profitable industry to the inhabitants of the town after the closing of the mill. They were said to assay from 5 to 10 ounces per ton, and were concentrated by hand jigs to 30 ounces per ton. It is said that about $200,000 was gathered in this manner. A carefully prepared sample of these concentrates gave upon analysis in the laboratory of the Survey in Denver 0.13 per cent of sulphur, and as the ore averaged only 35 ounces of silver per ton, or 0.12 per cent, it is seen that there was enough sulphur present to form the combination with silver required for any of the various mineral sulphides. The two mills cost about $300,000.

Game Ridge Mill.—This very complete and substantial Fraser and Chalmers 40-stamp wet-crushing mill, built on the same general plan as the Silver Cliff No. 2 mill, was erected on the east slope of Game Ridge, about a mile northeast of Rosita, to work the ore of the Game Ridge mine. This mine had about 500 feet of shafting and tunnels, but no definite ore body had been found, though some of the rock contained a little horn silver. The mill was completed in March, 1882, but no ore being ready for reduction, after the engineers had made a few revolutions to test the machinery, it was closed down and later dismantled and moved away. It cost about $150,000.

The Star Mine Smelter.—Sometime during 1882 the skeleton of a 10-ton water-jacket blast furnace was taken to the Star mine for the purpose of working its ores, but was never completed. This mine is on Oak Creek, to the northeast of the area mapped.

The above-mentioned "monuments to buried capital" are estimated to have cost more than $1,000,000. But a very small proportion seems to have been even partially successful, and as far as can be judged from the few facts above presented the failures in most every case can fairly be attributed to the neglect of the ordinary precepts of mining, to lack of business prudence, or to the ambition that possesses many men who embark in mining enterprises to prove themselves wiser than the knowledge that has been accumulated by years of scientific investigation and experiment the world over, and which is transmitted in the course of his studies to every well-trained mining engineer or metallurgist.

PRODUCTION.

It is more than usually difficult to obtain even an approximate estimate of the amount of metals produced in this region, for the reason that the mines have been worked with little regularity, that their ownership has changed many times, and that upon the disorganization of a company the records have been carried away and can no longer be found. After a few fruitless efforts to get access to such records the attempt to obtain any more accurate estimates than those furnished by the reports of the Director of the Mint has been abandoned. The latter are given in the following table. The product prior to January 1, 1881, is taken from the Silver Cliff Mining Gazette, in which gold and silver are not segregated. A probable segregation has been made by the writer. For the year 1885 no figures are given by the Mint reports, and those given in the table are estimates pure and simple.

Precious-metal production of Custer County up to January 1, 1895.

Period.	Region.	Gold.	Silver.	Total.
1880 *a*	Bull-Domingo		$290, 000	$290, 000
	Silver Cliff plateau		566, 956	566, 956
	Rosita and vicinity	*b* $350, 000	*b* 1, 016, 025	1, 366, 025
1881	Custer County	100, 000	700, 000	800, 000
1882	do	200, 000	300, 000	500, 000
1883	do	620, 000	200, 000	820, 000
1884	do	337, 788	244, 445	582, 233
1885	do	*c* 25, 000	*c* 100, 000	125, 000
1886	do	21, 600	90, 188	111, 788
1887	do	614	159, 855	160, 469
1888	do	120	5, 720	5, 840
1889	do	1, 200	104, 890	106, 090
1890	do	*d* 110, 500	164, 176	274, 676
1891	do	51, 000	62, 522	113, 522
1892	do	340	12, 638	12, 978
1893	do	4, 000	36, 709	40, 709
1894	do	165	1, 501	1, 666
		1, 822, 327	4, 055, 625	5, 877, 952

a And prior years.

b Probable segregation of gold and silver made by the writer.

c Estimates made by writer.

d This gold product, which is credited to the Pioneer mine, is of very doubtful accuracy.

Of other metals produced, lead is the only one of importance, and the Bull-Domingo is the only mine within the area mapped that has produced any considerable amount of this. Outside this area, but still within the county, the Terrible mine, at Ilse, on Oak Creek, has produced $759,717 worth of lead, according to the Mint reports, which has all gone to a single smelter.

CHAPTER II.

ROSITA MINES.

In Pl. XXXII of Mr. Cross's paper on the geological structure of the region may be seen a panoramic view of Rosita and the hills inclosing it on the north and west, which shows quite distinctly the relative position of the various groups of mines. The general position of the Humboldt-Pocahontas vein can be traced by the several shafts and dumps from the Virginia shaft, just back of the town on the right, to the Leavenworth mine, at the other extremity of the vein, high up on the slopes of Mount Robinson, at the head of the west fork of Hungry Gulch, in the middle distance.

The dump of the Maverick (formerly Senator) mine can be distinguished at the west end of the low ridge or shoulder back of the town on which the Virginia shaft is situated. As will be seen by reference to the geological map (Pl. XXVI), this ridge or shoulder is formed by a dike-like body of trachyte which cuts across the Rosita andesite that constitutes the base rock in the valley, while the hill back of the Humboldt mine is capped by trachyte. Pringle Hill, on the left, consists of the Pringle variety of andesite.

GEOLOGICAL HISTORY.

As appears from Mr. Cross's investigation of this region, the volcanic phase of its geological history commenced with the Rosita andesite eruption, which poured its lavas out over the preexisting hills and valleys of Archean rocks. There was probably an active volcano somewhere near the present site of Rosita which emitted lavas, alternating with ashes and fragmental material. The rock is a mica-hornblende-andesite, as a rule much altered. In the valley of Rosita Creek its characteristic appearance is that of a purplish or bluish-gray breccia. Near the mines it is often soft and somewhat bleached.

Succeeding the Rosita andesite eruption came those of the Bunker andesite, the Bald Mountain dacite, and the rhyolite, but except a few outlying dike-like bodies of the rhyolite these rocks do not appear in the immediate vicinity of Rosita.

Following these was the quiet eruption of Pringle andesite, which must have covered the entire southern slope of the hills, and of which a remnant still covers a great part of Pringle Hill west of Rosita. This rock is relatively fresh, yet sometimes kaolinized.

The next eruption was of trachyte, which now forms the cap rock of Game Ridge and a series of dike-like bodies which cut the Pringle andesite as well as the earlier rocks. The Game Ridge body fills an original but probably rather shallow depression, though its present outlines are in considerable measure determined by later faults. The location of the vent through which this rock was outpoured does not appear, but it may well have been some one of the dike-like bodies. The rock of the dikes is a dark gray porphyry, which has glassy sanidines when fresh.

ORE-BEARING FISSURES.

The ore-bearing veins cut the trachyte, thus proving their mineralization to have been subsequent to its eruption. In most of the faults which cut the trachyte some mineralization may be observed, and many of the prospects around Game Ridge found their ore in fault fissures. Such are the Horton and Hard Cash, on the California fault, and the Nellie and Sleeping Pet, on the Nellie fault, which are between trachyte and gneiss. On the Twenty-six fault, which is partly in trachyte and partly between Rosita andesite on the north and trachyte on the south, are the Summit, Polonia, and Twenty-six mines. This fault is a complex of parallel fissures, with crushed and shattered material between. In the vein itself are bowlders of andesite breccia and of granite, rounded by attrition.

The ore of the Twenty-six mine shows a most excellent comb structure, combined with a sheeting of the country rock, and affords good evidence of partial replacement of the sheeted bands of country rock material within the vein fissure by silver minerals. On one specimen of high-grade ore, carrying 200 to 300 ounces of silver to the ton, which gave the cross section of a vein opening about 4 inches wide, the succession from either wall inward observed on one face of the specimen was: First, a band of mixed spar and pyrite, with an irregular longitudinal vug-like cavity in the middle; second, a sheet of banded country rock, on the inner side of which was a zone of silver sulphide, while the center of the vein space was filled with white crystalline barite. On the other face of the same specimen the banded country rock had almost entirely disappeared, and its place was filled by silver sulphides, so that the three bands on either side of the central zone of barite were reduced to two—silver sulphides and a zone of spar and pyrite.

The so-called Game Ridge mine was entirely in the trachyte, though not far from its contact with the gneiss. It lies beyond the boundaries of the map. The workings cut several small veins of quartz, some of which carried horn silver. They are undoubtedly small fracture planes, but do not appear to have had much displacement.

The Senator (now Maverick) mine, noteworthy as having been the first discovered in the district, is situated on the east side of Hungry Gulch, just above the town of Rosita. Its main vein runs nearly east and west in the trachyte dike, which it crosses at a very acute angle.

It is not deflected or affected in any way, as far as has been observed, on passing from the trachyte into the andesite. The earlier mine was abandoned at a depth of 50 to 60 feet, after very rich ore had been taken, because the vein was supposed to have given out. In later years, under a new name, it has been worked by leasers, and about $50,000 is said to have been taken out, though the workings had not yet reached a depth of 100 feet. Two parallel veins are now known. The ore is in part a replacement. The trachyte near the vein is porous, from the removal of feldspar crystals, and these are often replaced by galena and other minerals.

HUMBOLDT-POCAHONTAS VEIN.

This vein affords an excellent example of what is generally called a true fissure vein. It is remarkably regular in direction and dip in its upper levels, and contains, in the length of about 4,000 feet along which it has been explored by underground workings, a rather unusual extent of rich pay ore.

As the various mines upon this vein had already been worked for a considerable time before our visit, some of the essential facts with regard to them are taken from the excellent descriptive article of Mr. R. Neilson Clark,[1] a well-known mining engineer, who was quite familiar with their workings in the early days up to the time of his writing in 1878.

The Humboldt-Pocahontas vein trends north 50° west; its pitch is to the southwest, or away from the hills, at an angle varying from 18° to 30° (from the vertical). The ore body in the South Leviathan claim was merely a portion of that in the Pocahontas that extended across the dividing line. About 50 tons of ore, averaging $86 per ton in value, had been taken from the claim, its shaft having been sunk to a depth of 171 feet. The Leviathan vein had also been worked on this property. The ore body of the Virginia claim, on the other hand, was not connected with that worked in the Humboldt-Pocahontas ground. The discovery of ore was here made on a small parallel fissure 30 feet from the main vein on the foot-wall side. The main shaft was located on a rich chimney in the main vein 90 feet from the Humboldt line. It had been sunk to a depth of 355 feet; 179 tons of ore of a value of $18,548, or $103 per ton, had been extracted, but difficulties had been caused by what Mr. Clark considered a fault which changed the dip of the vein for a certain distance to 30°. It had, however, resumed its average dip of 60° before working had ceased, and the pay streak with its accustomed clay gouge had come in again.

POCAHONTAS MINE.

It having been found that the original discovery shaft was within the Humboldt property, a "miners' meeting" was held to consider the question, which was finally left to arbitration, with the result that the 230 feet by which the two claims overlapped each other was divided between

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[1] Trans., Am. Inst. Min. Eng., Vol. VII, May, 1878, pp. 21-33.

them, making each claim 1,385 feet long. Thus an expensive lawsuit was wisely avoided.

This mine had been opened by two shafts on the vein, and one vertical shaft and several tunnels in the hanging wall country. Ore had been extracted down to the 300-foot level. There had been shipped up to January 1, 1878, 2,559 tons of ore of a value of $317,477, an average of $124 per ton.

HUMBOLDT MINE.

This claim was originally sold for about $25 worth of provisions. When the shaft was 14 feet deep one-half was sold for $100. When 100 feet of depth had been reached an eighth was sold at the rate of $40,000. At 175 feet of depth a half was sold for cash at the rate of $64,000 for the property. This was in September, 1875, and in the following month a company was organized which paid all of its capital stock for this and the adjoining South Humboldt and West Virginia claims, aggregating 1,900 feet on the vein. The only working capital of the mine was the few tons of ore on hand at the time of the purchase. This, however, was made to suffice, and as no other means of raising money, such as assessment or sale of additional stock, has been resorted to, the mine has the most unusual record of having been self-supporting from the start. The shaft was, in May, 1878, 420 feet deep. There had been shipped 2,108 tons of ore of a value of $225,604, or $107 per ton. The aggregate quantity and value of ore shipped from the vein is given in the following table:

	Tons shipped.	Currency value.	Mill returns.	Average value per ton.
Southeast Leviathan	50	$4, 300	$2, 100	$86. 00
Pocahontas	2, 559	317, 477	171, 248	124. 00
Humboldt	2, 105	225, 604	132, 145	107. 00
Virginia	179	18, 548	9, 821	103. 00
Total	4, 893	565, 929	315, 314	115. 66

The ore is mainly barytic-tetrahedrite, carrying copper and iron pyrites, some galena, stephanite, and other antimonial silver minerals. Barite is the principal gangue mineral, calcite being in subordinate amount.

The vein has a remarkably regular and smooth hanging wall, but the foot wall is less regular and often swells from the hanging wall. The gangue is a soft clay (altered country rock), and a clay selvage is found on the hanging. A parallel fissure carrying some mineral is found in the foot-wall country in the southeast end of the mine, at a distance of about 25 feet from the hanging wall, and the intermediate country was considered by some to constitute part of the vein. Mr. Clark also remarked on the fact that a change of rock and apparent fault came in near the Humboldt and Virginia shafts respectively, which were situated opposite ravines or depressions in the hills to the north. He says there is no appearance of any especial disturbance at either place, but the vein matter became for the most part of no value at these points. The writer has not been able to verify these observations of Mr. Clark with regard to the faults, but it is significant that in the former case, at any rate, it is on a line with a depression in the hills to the north which corresponds in part to a line of faulting.

Mr. Thornton has informed the writer that in the second level, running southeast from the Humboldt shaft, work was stopped at what was supposed to be a fault. A drift running in the opposite direction from the Globe shaft found no such interruption or appearance of faulting, but was stopped before connection was made because the vein became thin and poor. On the next lower (third) level the drift from the Humboldt shaft was driven continuously to the Globe shaft, the vein being apparently continuous, but curving out to the northeastward and becoming thinner in the region of supposed faulting. The hanging wall in this part of the mine was unusually hard, and crosscuts into the foot-wall country found granite bowlders not infrequently inclosed in the breccia.

The elevation given in fig. 38 shows the relative position of the shafts, and in a very general way the portions of the vein that carried rich ore. The latest workings are, however, not indicated.

The Pocahontas and Humboldt mines were examined by the writer in 1883, and again visited in 1887. At the latter date the former mine was worked through the shaft of the latter, on its 300-foot level (see elevation, fig. 38), and it is not known whether the vein has since been worked to greater depths in the Pocahontas ground. Above this level the vein was remarkably regular and straight in the Pocahontas ground, having a northwest-and-southeast strike and an average dip of 45° to the southwest. The country rock on either side is Rosita breccia, sometimes losing, however, its brecciated structure and showing only solid lava, especially on the hanging wall. The breccia is often quite dark-colored and hard; at other times bleached and decomposed. The hanging wall is especially well-defined, smooth and regular; it generally has a thin clay gouge or selvage. The vein matter is for the most part decomposed country rock, impregnated with pyrite, chalcopyrite, tetrahedrite or gray copper, and some silver sulphides and antimonides, associated with barite, often in fine tabular crystals. Its width varies from a few inches to 2 feet. The foot wall is wavy and has no clay gouge, though it forms a comparatively distinct separation plane between ore and country rock. The pay ore is said to run in horizontal streaks and to have been continuous from one end to the other of the Pocahontas claim.

In the Humboldt ground the vein is of the same general character, but its dip varies from 45° to 70°. The shaft has followed the average dip of the vein (i. e., 60°) to the fourth level, where it split. Bowlders of granite and gneiss could occasionally be observed completely inclosed in the andesite country rock. Down to the fourth level (400 feet on the dip) the vein is comparatively regular. Below that level a horse of country rock about 30 feet wide divides it into two. The northeastern vein gradually assumes a steep dip and becomes reversed, having a pitch to the north. For some distance it is said to have gone down in a series of steps that were alternately very shallow and very steep. From the fifth level down the northeasterly vein had granite on the hanging or northeastern wall and on the other wall breccia gave place to porphyry. The ore became mostly pyrite of rather low grade—20 to 30 ounces of silver per ton. The southwestern or main vein, on the other hand, grew shallower in dip, and diverged from the other until at the eighth level they were nearly 800 feet apart. The crosscuts between the two were in broken rock until the seventh level was reached, when it became solid porphyry, which showed a regular sheeting parallel to the southeastern vein. The northeastern vein gradually died out, and the southeastern or main vein was thought at one time to be lost, but was recovered on the eighth level. Here the breccia had disappeared and the same even-grained porphyry appeared on both walls. In the vein were found here and there rounded fragments of red granite

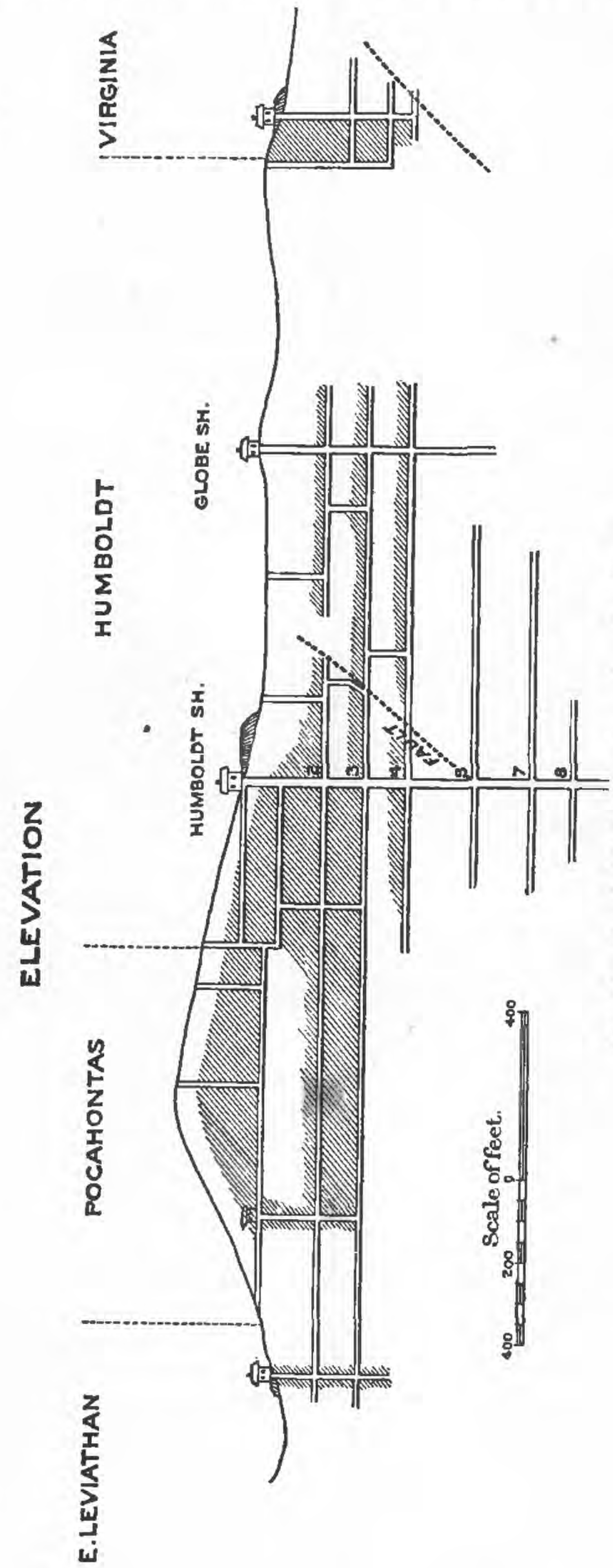

FIG. 38.—Humboldt-Pocahontas vein; elevation.

of various sizes, sometimes entirely coated by gray copper. In one case the granite fragment was so large that it took quite a long time to cut a drift through it.

The facts with regard to these lower workings were obtained in 1887 from the manager, Mr. Thornton, an extremely careful and intelligent observer. At that time they were full of water, having been abandoned by the owners on account of the low grade of the ore and of the shallow angle of the vein, which rendered the drift difficult to ventilate and drain. The lowest point accessible at time of visit was the fifth level, where, 50 feet south of the shaft, a body of porphyry (presumably trachyte) cut off the breccia and vein at right angles. A crosscut along this body found, 50 feet to the northeast, an irregular contact of porphyry with a breccia containing large fragments of granite. This contact or vein had the normal strike of the Humboldt vein, with a vertical or slightly reversed dip. A cross cut to the southwest found the contact between porphyry and breccia at 80 feet from the line of the shaft, which dipped 30° to the southwest and was apparently the normal continuation of the Humboldt vein. Between these two veins the rock was porphyry, but so altered that it was impossible to determine whether it was trachyte or andesite. It was crossed by small stringers or slip planes parallel to the main vein, which carried a little ore, and in the middle was so broken up as to resemble a friction breccia. It is possible that the porphyritic rock is a portion of an offshoot from the trachyte dike which forms the low ridge between the Humboldt shaft and the town of Rosita, and which, if it extends vertically downward, would be cut by the southwestern branch of the Humboldt vein (see fig. 39). This dike, as shown on the map, crosses the line of the vein just west of the Virginia shaft, which may account for its barrenness at that point.

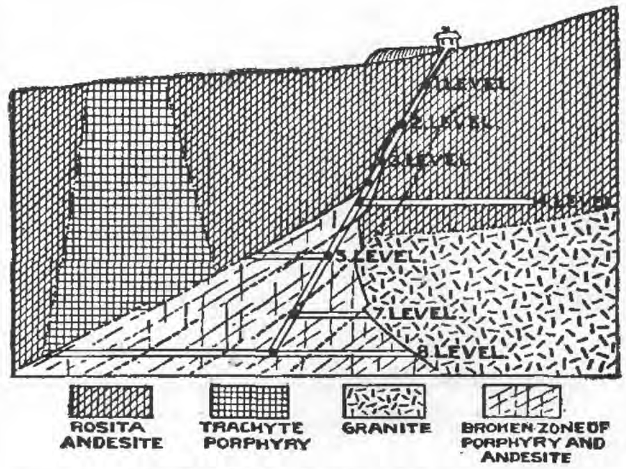

FIG. 39.—Humboldt-Pocahontas vein; cross-section.

In the upper workings the Humboldt ore body is said to have extended in practical continuity nearly to the Virginia line, a distance of about 1,600 feet. The Virginia mine was not accessible at the time of visit, and the only data obtained with regard to it were taken from Mr. Clark's description, already quoted. It appears from these statements that where the trachyte crosses the vein it pinches and becomes poor, and this appears to be the case in the lower part of the Humboldt. How far, if at all, the vein has been explored in the lower levels in the Pocahontas and Virginia grounds is not known, bnt it may be assumed from the fact that, as they are no longer worked, it was poorer there than above

LEAVENWORTH AND PIONEER MINES.

The Leavenworth vein is part of the same fracture system as the Humboldt-Pocahontas, and very probably a continuation of the same vein, though the continuity has not been actually proved. The workings of the Leavenworth mine are on the south slope of Mount Robinson, at the heads of Leavenworth Gulch and of the west fork of Hungry Gulch. Its general course is northwest and southeast, changing at the east end to north 75° west and on the west end bending to the south of west down Leavenworth Gulch, where it is soon lost. It average dip is 45° to the southwest, but this steepens in depth to 60°. It is often a mere knife-edge crack filled with clay; its maximum thickness is about a foot. It carries the same mineral species as the Humboldt vein, together with abundant barite in tabular crystals. Here, however, it is the foot wall that is well defined, the andesitic breccia being hard and compact and impregnated with fine-grained pyrite, while the hanging-wall country rock is changed to a white, clayey material, so that its original character is difficult to determine. In the early workings the mine was opened down to 300 feet in vertical depth, and is said to have produced about $120,000 in silver.

In later years it has been worked anew by leasers in connection with the Pioneer vein, which crosses it, or branches from it, having a strike of north 15° west and an average dip of 65° to the east. The ore, as is very apt to be the case, is concentrated on either vein mainly near their intersection. In 1888 the workings had reached a depth of 400 feet, and the ore body extended 40 to 60 feet from this intersection on the Pioneer vein and up to 200 feet on the Leavenworth. In the production of later years the Pioneer mine is credited by the Mint reports with a production of $110,000 in gold and $37,000 in silver. With regard to the accuracy of the former figure there is very great doubt, as no considerable gold values have hitherto been found in this region outside of the Bassick mine.

DISCUSSION.

It is greatly to be regretted that the lower parts of this vein could not have been examined in detail over its entire extent, for from what has been learned about the deeper portion near the Humboldt shaft it would seem that an opportunity is here offered of studying the root of an extensive and well defined system of vein fissures. It has long been the opinion of the writer that the idea generally accepted among miners that, because an ore deposit has been formed on what may be called a true fissure vein, it necessarily has an indefinite extension in depth, is much in the nature of a popular fallacy, and that the extension in depth in a fissure vein is as likely to terminate within a measurable distance as the extent of ore deposition on what are generally called blanket deposits. The present case seems to illustrate this idea as far as facts enable one to judge, for while the fault fracture constituting the vein has been traced horizontally over a mile, where it has been explored in depth it splits and shows signs of dying out altogether at 800 feet from the present surface. To this depth should be added, for the original vertical extent of the fault fracture, the amount that has been carried away by erosion since it was formed. As to how much this has been there are but few facts available for forming a valid deduction, but in all probability it can hardly have been much over 1,000 feet.

It is rare that an important fault movement takes place on absolutely a single plane, and in this case there have been evidently one or more parallel planes of movement which have not been thoroughly explored, probably because the main vein was so regular and well defined, for the miner generally likes to follow a well-defined wall and is reluctant to go behind it. In the present case it is possible that more ore might have been found on one of these secondary planes in the upper workings.

The vein appears to split into a series of conjugated fractures in depth in the Humboldt ground as it reaches the porphyry (trachyte?) and granite. The diagrammatic section given in fig. 39 is founded on too few facts of observation to be claimed to be accurate, but it represents a probable manner in which the main fault fracture splits up in depth.

In the case of the Comstock and some other important veins, the vein fissure has split and opened out upward toward the surface. For this reason miners are apt to expect that two nearly parallel veins which are in proximity at the surface will be likely to come together in depth. In the present case the conditions are reversed, showing that the splitting is not necessarily upward in every case. If the ore-bearing currents were ascending along a set of fissures such as is represented in the section, it is readily conceivable that the richest and most abundant ore would be concentrated in the upper part after the converging fissures had united.

CHAPTER III.

THE BASSICK MINE.

Mount Tyndall is an extremely picturesque conically shaped hill situated at the northeastern extremity of the eruptive area of the Rosita Hills, whose summit rises about 600 feet above the surrounding valleys. On its southern slope, just above the town of Querida, is a secondary hill or shoulder on which is situated the outcrop of the ore body of the Bassick mine. Pl. XXXV of Mr. Cross's paper is the reproduction of a photograph of Mount Tyndall from the south, and shows this shoulder and the location of the Bassick shaft house.

The geological structure of the immediate vicinity of this mine is set forth in considerable detail in Mr. Cross's paper, and illustrated by a special geological map (Pl. XXXIII) and a sheet of cross sections (Pl. XXXIV), on which the probable outlines of the different bodies of eruptive rock are projected downward. It will not be necessary here, therefore, to give more than a very brief outline of the geological structure of the region.

The agglomerate which incloses the ore body and forms the entire mass of Bassick Hill and a considerable proportion of that of Mount Tyndall contains fragments of andesite both of the Rosita and of the Bunker types; hence it must be of later formation than either of these rocks. It is a true agglomerate, formed mainly of andesitic material. The top of Mount Tyndall is formed of a dense, banded rhyolite that rests on Rosita andesite tuff, part of a flow which extends out over the Archean to the west. This rhyolite has protected the underlying formation, which is soft and easily eroded, while Bassick Hill, as the shoulder already mentioned is called, has resisted erosion because of the silicification of the agglomerate in the vicinity of the ore body. In the upper knoll on the ridge connecting Bassick Hill with Mount Tyndall is a dike of dense black rock, 3 to 4 feet wide, described as limburgite, in which fresh olivine crystals are the only phenocrysts. This dike is of special interest, since, as Mr. Cross has shown, the Bassick ore body must have been formed previous to its eruption.

The fragments in the agglomerate vary in size and form. Some are rounded, others subangular; few, if any, are distinctly angular. Their size varies from that of gravel stones to blocks 3 feet in diameter. In the quarry above the Bassick mill, where the exposures are good, the matrix is white, often homogeneous in appearance; here it is hard and flinty, there earthy and crumbling. When the residual products, silica and kaolin, are locally concentrated it sometimes forms a conglomerate.

Sections on Pl. XXXIV of Mr. Cross's paper show the assumed form of the agglomerate body and of the volcanic neck which it is supposed to fill. Of the actual outlines below the surface there are very few facts to show the probable form, but volcanic necks in general have nearly vertical walls, and at the depth of 1,400 feet in the Bassick mine this agglomerate shows no evidence of near proximity of the Archean, so that there is as yet no means of knowing its form or extent in depth.

The Bassick ore body was discovered, as has already been stated, in 1877. The ore was so very rich at the surface that although the discoverer after whom it was named was a poor man, he found no difficulty in raising money almost on the spot for opening it. It has been far and away the richest and most productive mine in the district. According to the Silver Cliff Mining Gazette, it had produced up to January 1, 1881, a half-million dollars in gold and silver. Of the million and a quarter dollars' worth of gold and nearly a million and a half of silver credited to the district for the four succeeding years, most all the gold and a very considerable proportion of the silver were probably produced by this mine.

The mine was originally opened directly from the surface by a vertical shaft following the ore body downward. At 150 feet this was connected with the surface by an adit level or tunnel, and the ore was extracted through this tunnel, whose track runs directly to the concentration works. From the tunnel level a shaft was sunk vertically, on which the levels are reckoned as from the tunnel level, since the ore was not hoisted above that level.

MODE OF OCCURRENCE OF THE ORE.

At the time this investigation was commenced the shaft had already reached the 800-foot level, and the workings on the upper levels were mostly timbered up and the outcrops obscured by shafts and dumps, so that there was little opportunity of studying the manner of occurrence of the ore. For the purpose of supplying this want the following is compiled from the excellent description of the mine made in 1882 by Mr. L. R. Grabill,[1] who had for some years been connected with it:

The fissure itself is an irregular opening, nearly elliptical in horizontal section, and varying in dimensions from 20 to 30 feet on the shorter diameter to nearly 100 feet on the longer. Downward it extends for nearly 800 feet vertically, though winding slightly. No walls have been found, nor any distinct boundaries between the ore and the country rock. The ore is richer near the center of the body, the layers or scales of mineral being there thicker and containing a larger proportion of the precious metals. As the edge is approached these become thinner and poorer until the ore is too poor to work. The size

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[1] On the peculiar features of the Bassick mine, by L. R. Grabill: Trans., Am. Inst. Min. Eng., Vol. XL, 1882, p. 110.

of the rounded fragments of porphyry (andesite) is also greater near the center of the body, which leaves larger interstitial spaces in which the combs of mineral can be formed. The pebbles or rounded fragments become smaller and the mineral scales thinner as the distance from the center increases, until the scales entirely disappear. Traces of the precious metals still continue for some distance, and these, too, finally disappear.

The minerals noted were sphalerite, galena, jamesonite, tetrahedrite, smithsonite, calamine, free gold, quartz. No barite, calcite, nor any one of the usual spars or crystalline alkali-earth minerals are found in the deposit.

The bowlders around which the scales of mineral were deposited vary in diameter from 1 to 60 centimeters. The most common sizes have diameters of 10 to 30 centimeters. They have no sharp or rough edges or corners, and their shape is often approximately spherical. They appear to have been much worn by water or friction before the deposit of minerals took place.

The mineral is arranged in concentric shells around and parallel to the surface of the bowlders. These shells or layers follow each other in the same order, and are of about the same proportionate thickness. Usually three, sometimes four distinct layers can be distinguished. They are from within outward:

First. A thin layer consisting of sulphides of zinc, antimony and lead, with metallic luster, black color, crystalline structure, and hardness of about 4. It is from a hair line up to 5 millimeters in thickness. It usually carries about 60 ounces of silver and 1 to 3 ounces of gold to the ton.

Second. A layer lighter in color and containing more lead, silver, and gold than the preceding. It sometimes contains as high as 100 ounces of gold and 150 to 200 ounces of silver to the ton.

Third. A shell of sphalerite, beautifully crystalline, which also shows a considerable amount of iron and some copper. This constitutes the principal source of value in the mine. It is from 5 millimeters to 5 centimeters thick, and usually contains 60 to 120 ounces of silver and from 15 to 50 ounces of gold to the ton. This is often the outer coating of all and is rough on the outside.

Fourth. The next shell, when there is one, is formed of chalcopyrite. It is very variable, and consists sometimes of sparse crystals scattered over the rough surface of the sphalerite. Sometimes it attains a thickness of 1 or 2 centimeters. It carries up to 50 or 100 ounces of gold and silver.

Fifth. Outside of all there sometimes occurs a thin coating or sprinkling of pyrite crystals. In the larger interstices and filling crevices between the bowlders is kaolin.

Of these the first, or thinnest, scale is always present, being the inner shell of the coating on larger bowlders, as well as the sole covering of the smaller pebbles. This is an antimonial sulphide of lead resembling jamesonite. On the other hand, the sphalerite shell is wanting in the outer part of the ore body.

Of the other minerals the calamine and smithsonite and most of the free gold are found above the water level. The tetrahedrite never occurs as a shell, but always fills vacancies outside the coated bowlders and intermingled with quartz. It is impure, and broken pieces of the first and second coatings (but never of the third and fourth) are sometimes mixed with it. In the same mass the tellurides of gold and silver are contained. Tellurium was determined by chemical test in two specimens—in one 0.05 per cent, in the other 0.08 per cent. This ore contains 200 to 300 ounces of gold and 100 to 200 ounces of silver.[1]

Quartz is found in the open spaces between bowlders, never within the bands. It is mostly amorphous, and ranges in color from opaline white, through gray, blue, and brown, to black.

Charcoal has been discovered both within and without the ore shoot, down as far as 765 feet. The amount found at this level would make a cubic foot. It was most common near the water level. It is mostly soft and friable, though still showing the grain of the wood. Some is much silicified. Nearly all had the pores filled with glittering crystals of pyrite. One piece 3 to 4 centimeters long showed the cross section of a tree or branch 4 to 5 centimeters in diameter.

Dr. Grabill remarks on the fact that the bowlders are rarely in contact with each other, and is unable to account for this phenomenon, as he does not see what could have supported or kept the fragments apart while the metallic shells were being deposited around them.

At the time of this examination the ore was being taken from lower levels than were opened at the time Mr. Grabill wrote, and it was therefore impossible to obtain as complete a series of specimens of the ore as was accessible to him. Hence it is not surprising, and casts no doubt on the accuracy of his observations, that we were unable to verify them in every respect. Neither free gold nor the oxidized zinc minerals were observed, nor were tellurides detected. The more common minerals observed were pyrite, sphalerite—both the dark ferruginous and the yellow resinous varieties—galena, and chalcopyrite. In some cases the different bands were separated by a thin earthy band carrying some calcite or dolomite, which often contained a flat, open space parallel with the banding. The elongated vugs found sometimes in the bowlders of country rock are generally lined with minute crystals of calcite or dolomite, but where one of these vugs is cut off by the metallic band around the bowlder a thin film of pyrite lines the vug near its mouth, which is in turn covered by bluish chalcedony that lines all the interior parts of the vug.

The bowlders within the area of ore deposition are generally bleached and decomposed; they have lost most all traces of their basic silicates, and their feldspar crystals are thoroughly kaolinized. On the other

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[1] This amount of tellurium is only sufficient to combine with less than one-tenth of the amount of gold and silver given above to form known telluride minerals.

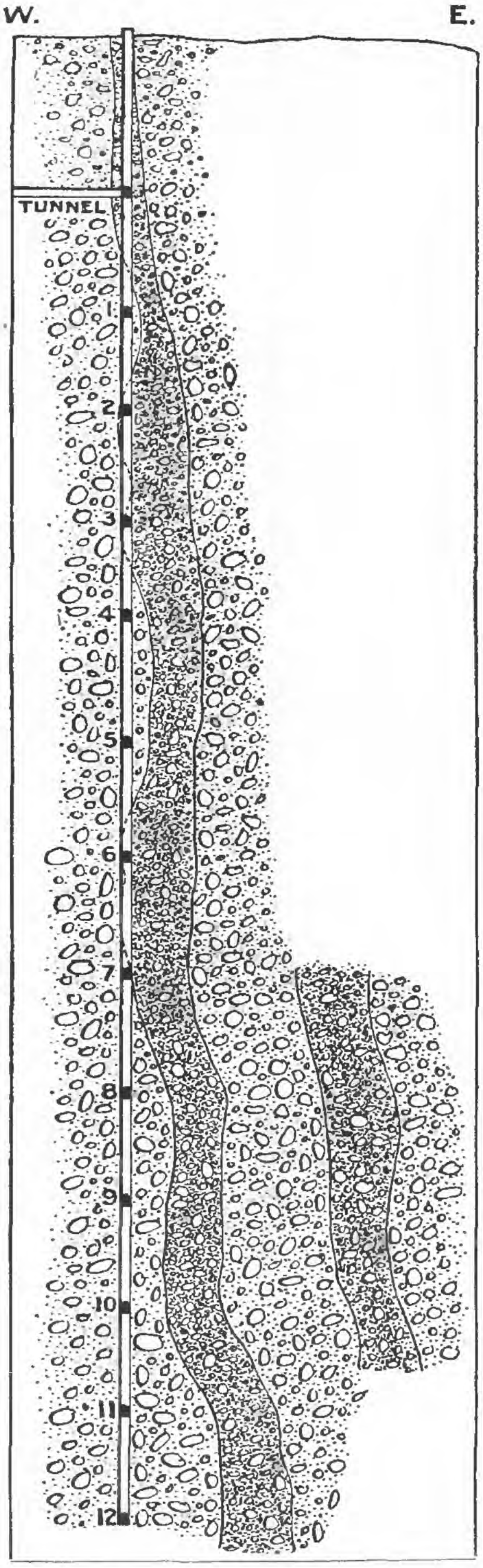

FIG. 40.—Bassick mine; cross-section of ore body on an east-west line.

hand, they are very frequently impregnated with pyrite, which, coarser and more abundant near the periphery, decreases and becomes finer grained toward the interior.

In the barren breccia surrounding the ore body, the interstitial spaces between the larger fragments of andesite are filled by a bluish siliceous mass which incloses, also, smaller fragments of the country rock. It is in part a finely granular mass, in part compact, approaching chalcedony. The latter contains no metallic minerals, but fine-grained pyrite is scattered through the granular portions, and still more abundantly through the interior of the fragments where it seems preferably to replace the basic silicates, but never completely to fill the spaces originally occupied by them.

Although there is no definite boundary between the ore and the barren breccia, it was observed that there were several fracture plains or joints in the agglomerate, cutting each other in such a way as to rudely outline the form of the ore shoot.

As the mine was permanently closed down before a second visit to the district was made, no personal observations of the lower levels were possible. From the superintendent and foreman the following facts with regard to them were, however, obtained: A second ore body or shoot was struck to the east of the main body when the shaft was down to the tenth level. and the two ore bodies were thought to be approaching each other. The ore in the new body carried rather more zincblende than the first shoot, and below the tenth level the ore formed a thinner scale about the bowlders, and was supposed to contain a considerable amount of tellurium.

In the 1,200-foot level (below the tunnel) the ore was 4 inches thick around the bowlders, and the new shoot was 150 feet from the old one, but not developed at time of closing.

In fig. 40 is given a somewhat diagrammatic section of the two ore bodies on a line running east and west through the shaft. It was obtained from the intersections of the sets of timbers that fill the old stopes at each of the levels. These, of course, represent only the limits of the pay ore, and that not always with perfect accuracy. Hence the main merit of the section is to show the general form and direction and the approximate limits of the pay ore.

In further confirmation of Mr. Grabill's estimate of the character of the ore, the writer has been informed by Mr. Richard Pearce, manager of the smelting works at Argo, near Denver, that these works were the first to purchase Bassick ore, and that he found tellurium in it. He furnishes, further, the following analysis of a piece of rich Bassick ore, made by Mr. F. C. Knight, chemist of the Argo works.

I.—*Analysis of rich ore from Bassick mine.*

	Per cent.
Gold	a1.64
Silver	b2.38
Copper	17.43
Zinc	18.19
Lead	10.18
Iron	7.96
Bismuth	.56
Tellurium	2.72
Sulphur	26.07
Arsenic	1.90
Antimony	10.20
Total	99.29

a 475.32 ounces to the ton. b 694.15 ounces to the ton.

This piece of ore was apparently made up of tetrahedrite, chalcopyrite, galena, sphalerite, and possibly petzite.

GENESIS OF THE ORE.

In spite of the meagerness of the data there are two series of phenomena connected with this deposit that point very decidedly to an origin and manner of formation differing from that of the ordinary ore deposit. These are—

First. The physical character of the body, its form of a long, slender, nearly vertical chimney in an agglomerate which appears to have filled the neck or crater of an old volcano.

Second. The fact that in the composition of its ore the earthy minerals, such as barite, calcite, and quartz, which are common in the other ore deposits of the region, do not form an essential part of the vein material, but occur, if at all, only in subordinate amounts in the actual ore channel, and are apparently secondary ingredients introduced after the deposition of the other minerals.

The conclusion from these facts seems inevitable that the ore deposition was here a phase of the volcanic eruption; not, however, as has been suggested by some, that it took place during the active eruption of the volcano, and that the metallic vapors were condensed around the rock fragments as they were thrown upward and fell back again into the neck of the crater (for under such circumstances they ought to have impregnated the whole mass of the agglomerate), but rather as a phase of the dying activity of the volcano, after all explosive action had ceased, and when the agglomerate had cooled and become consolidated. It would seem that here, if anywhere, was presented a typical instance of a deposit due to fumarolic action, which is the explanation French geologists are wont to give to most deposits of metallic minerals in close connection with igneous rocks, an explanation that the writer has been unwilling to accept for most of the deposits he has studied.

As a result of the studies that have been made of gaseous emanations from the lavas of active volcanoes, mostly by French geologists, the following phases in fumarolic activity are recognized:

1. *Dry or anhydrous fumaroles.*—In these the gases issue quietly from the fused lavas at a very elevated temperature (500° C.) in the form of white fumes. They consist mainly of anhydrous chlorides. Chloride of sodium is most abundant (up to 94.3 per cent at Vesuvius), next chloride of potassium (up to 16 per cent), and small amounts of the chlorides of manganese, iron, and copper have been detected.

2. *Acid fumaroles.*—These issue from the sides of the lava stream at some distance from the still fused lava, and are at a less elevated temperature than the preceding (300° to 400° C.). They contain a mixture of sulphurous and hydrochloric acids, with enormous quantities (about in the proportions of a thousand to one) of steam. It is assumed that the temperature is not sufficiently elevated to remove the chlorides of the alkalis from the lavas.

3. *Alkaline (or ammoniacal) fumaroles.*—They are characterized by the presence of chlorohydrate (possibly also of carbonate) of ammonia. They consist mainly of aqueous vapor, and contain, also, a little sulphuretted hydrogen, and the temperature of the gas is about 100° C.

4. *Cold fumaroles.*—They consist almost entirely of aqueous vapor, and have a temperature inferior to 100° C. They contain sulphuretted hydrogen and about 5 per cent of carbonic acid, and might be designated sulphydric fumaroles.

5. Finally the *mofettes*, or emanations of carbonic acid, mark the close of the eruption. All these vapors contain atmospheric air, oxygen, and nitrogen; also hydrogen and sometimes hydrocarbons.

More briefly, the various phases in gaseous emanation may be characterized as (1) alkaline chlorides and hydrochloric acid; (2) steam and sulphurous acid gas; (3) carbonic acid gas.

The products that have been observed in the vicinity of lava flows that may be ascribed to fumarolic action are: Specular iron, chloride of lead or cotunnite, boric acid, and the sulphides of arsenic, realgar, and orpiment.

As both the gases and their products mentioned above have been formed under ordinary atmospheric pressure and with practically free access of atmospheric air, we are by no means justified in assuming that the same conditions prevailed in the conduit in which the deposit under consideration was formed, as part of it is, even now, nearly 1,500 feet from the surface, and in all probability nearly as much of the upper part has been eroded away.

The gases directly emitted from the fused lavas are, as is stated above, anhydrous. But it is not conceivable that such mineral products and in such forms as are found in the Bassick mine could have been produced by dry distillation. Indeed, the great French geologist, Élie de Beaumont, who was among the first to insist on fumarolic deposition, himself admitted that such deposition must have been through the agency of water, and could not have been a dry distillation. The metallic minerals in this ore body were evidently deposited mainly as sulphides and to a limited extent as tellurides; it seems, therefore, more reasonable to assume that they were formed during the closing phases of fumarolic activity, when H_2S and SO_2 were the prevailing gases, if indeed it was in the gaseous form that they were concentrated in their present locus. It is not impossible, however, that the aqueous vapors carrying the sulphides and tellurides of the minerals were under so great a pressure, at the depth at which most of the deposition took place, that if their temperature was not very much above 100° C. they were condensed into liquid form.

The brief examination that was made of the ore body showed two or more lines of fracture in the agglomerate, intersecting each other near the outer limits of ore deposition. Moreover, it is said that the second ore chimney, which has only been observed as yet in the lower levels, is on the same line of fracture or jointing that runs through one side of the main body. It would appear, therefore, that it was the intersection of certain fracture planes that determined the course of the ore-bearing channel, and that the ore body is not necessarily the center of the volcanic vent, but that, as a second ore chimney has already been discovered on one side of the first, it is by no means impossible that other chimneys or ore shoots may exist in the body of the agglomerate, which might be discovered by judicious and systematic exploration in the direction of the principal fracture planes.

It will be a matter of great interest to students of ore deposition to obtain accurate and detailed information with regard to this deposit, especially if it shall be explored to the great depth contemplated in the Geyser mine, and for which there is certainly as great a promise of profitable return here as there.

There is singularly little known of deposits to which a gaseous origin can with certainty be assigned. None have come under the observation of the writer previous to this, and, as has been stated above, he is inclined to admit the possibility that the ore deposition here was made from superheated sulpho-aqueous solutions that under ordinary atmospheric pressure would have assumed a gaseous form. Mr. Grabill failed to see how the shells of mineral could have inserted themselves between adjoining rock fragments or bowlders, when the latter were actually in contact, for at the time he wrote the capabilities of replacement action had not yet been so far demonstrated as to make it a common form of ore deposition, as it is admitted to be to-day. At the time of deposition the agglomerate in what is now the ore channel was probably in no essentially different condition from that in which the country rock around the ore body is now, except that it may have been somewhat shattered along the fracture planes that are supposed to have determined the course of the ore-bearing currents, whether of gas or liquid. The interstices between the fragments must therefore have been more or less completely filled by the finest tuff material, and this was removed as the metallic minerals were deposited, the ore-bearing materials eating through this more or less porous material until they reached the fragments or bowlders of compact lava, when they were precipitated on the periphery of these bowlders. Except for the absence of earthy gangue minerals, the results of this deposition differ in no way, as far as could be observed, from those that have been noted in deposits which were undoubtedly made from aqueous solution, and the resemblance extends to the more complete rounding of the rock fragments, which is an almost invariable result of the action of aqueous solutions.

CHAPTER IV.

THE BULL-DOMINGO MINE.

GEOLOGY OF THE BLUE MOUNTAINS.

The Blue Mountains are a group of isolated hills rising, monadnock-like, out of the gently sloping plains on the west flanks of the Wet Mountain range. Evidently they once formed part of the original Wet Mountain plateau, or peneplain, and have resisted erosion to a greater degree than the plains around them through the more enduring character of the rocks of which they are composed.

They consist of a central ridge of augite-gneiss of massive texture, with curving ridges branching off from the southern end, the western of which is of the same rock, while the eastern is more clearly banded and passes into hornblende and biotite-gneiss. In the depression between these and the central ridge is a white muscovite-gneiss, with neither hornblende nor biotite. The foliation has a prevalent strike between N. 40° E. and N. 75° E., with a dip of 40° to 90° to the northwest. In the northern part of the hills this strike bends more to the northwest. Dikes of granite, syenite, and diabase traverse these rocks. The former generally run parallel to the banding or foliation of the gneiss.

At the southern end a ravine running southward splits the group into two rather unequal parts. On the spur west of this ravine is a narrow dike of red fine-grained syenite, running about N. 25° E. and dipping 79° to the southeast. A short distance to the east of this dike is a somewhat thicker dike-like body of pink granite, which has strike to the northeast, with the foliation of the gneiss, and which dips 79° to the northwest. Within the angle formed by these diverging dikes and at the foot of the steeper slope of the hills was the outcrop of the Bull-Domingo ore body, now a round bowl-shaped hole 70 to 100 feet in diameter and perhaps 30 feet in depth. This ore body was discovered, as already stated, in 1879, soon after the discovery of the Silver Cliff deposit. It is about three miles north of the town of Silver Cliff and about 100 to 150 feet above the general level of the plains. When the ore body was developed it was found to be in part on two claims, the Bull and the Domingo, and the respective interests were soon consolidated and a company formed under the title of the Bull-Domingo Company, with a capital of $10,000,000.

CONCENTRATION PLANT.

A concentrator or ore-dressing mill was built for treating the ore on Grape Creek below where the town of West Cliff was later situated, a little over 2 miles from the mine. It was intended that this concentrator should be connected with the mine by a tramway, there being a continuous down grade from the mine to the mill. The building had an area of 107 by 45 feet, arranged on three floors at different levels. On the main floor were twelve Hartz jigs, with revolving screens above them, and three sets of Cornish rolls. On the next floor above was a large Blake crusher, which received the ore from the upper floor at the rear of the building. Two elevators and two dry screens above the Cornish rolls completed the concentrating apparatus, which, though simple, was sufficient for an ore that is unusually well adapted for concentration, consisting mainly of galena and some zincblende, with a gangue of calcite, dolomite, and more or less altered country rock.

Its nominal capacity was 100 tons in twenty-four hours, which appears to have been very nearly approached in actual practice. About 5½ tons of crude ore yielded 1 ton of concentrates, and the efficiency of the process is shown by the following table, giving the lead and silver contents of the ore and of concentrates:

	Crude ore.	Concentrates.	Tailings.
Silver .... ounces per ton..	10-12	40-44	1½
Lead .... per cent..	10	60-65	Trace.

MINE WORKINGS

A shaft was first sunk to a depth of 70 feet in the ore body and drifts run from that level in various directions through the ore, disclosing its form to be rudely that of half an ellipse whose longer diameter was about 80 feet. A new vertical three-compartment shaft was later sunk about 90 feet south and a little west of the first, and so much further away from the ore body, but in more solid ground. From this shaft levels have since been run at 150, 250, 350, and 550 feet from the collar, as shown in section on fig. 42.

At the time of this examination, in 1883, the workings had reached the 350-foot level. A somewhat remarkable fire occurred in 1885, which burned up the shaft house and the shaft timbers down to the cribbing on the 150-foot level, so that the shaft caved in. The fire started from too intense a fire under the boiler, which so heated the sheet-iron chimney that it set fire to the wooden roof through which it passed and soon communicated with the whole building. A stick of giant powder, which a miner had left to be warmed on the engine boiler, was exploded by the great heat of the burning roof and tore a hole 6 inches long in the top of the boiler. The machinery was at once disabled by the loss of steam pressure, and the air compressor which furnished air to the men who were sinking the shaft at the 550-foot level was stopped, so that, overcome by want of air and by the products of combustion, ten miners were suffocated.

After this the mine was worked somewhat intermittently, but closed down in 1889. In 1890 it was opened again by parties who took a long lease of the property, and was worked for awhile at a profit. It was visited by the writer during this year, and the workings on the 550-foot level examined. Since that time it has been again closed down.

PRODUCTION.

Data with regard to the product of the Bull-Domingo mine are, if anything, even more incomplete than those of the other mines here noticed. The Silver Cliff Mining Gazette gives $290,000 as the value of the product up to January 1, 1881, and the Mint reports credit it with $300,000 to $400,000 up to the summer of the same year. For the following years up to 1890 no segregated product is given, but for the subsequent years, when it was working under lease, a product of about $100,000 in silver and $75,000 in lead is given. It can only be said, therefore, that the total product has probably been something between $500,000 and $1,000,000 worth of silver and lead.

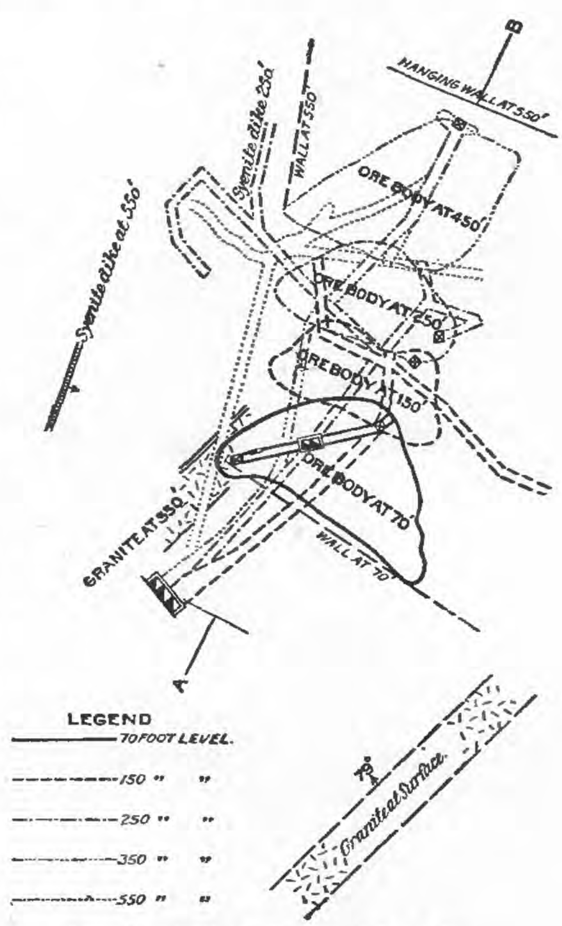

FIG. 41.—Bull-Domingo mine; plan.

MODE OF OCCURRENCE OF THE ORE.

The Bull-Domingo ore body has been generally classed with that of the Bassick mine as a deposit in a volcanic neck, a very unusual form of ore deposition. The ore itself is even more striking in appearance than that of the Bassick mine, consisting of concentric shells of brilliant crystalline galena and spar forming coatings around rounded bowlders of country rock.

The studies of this deposit made by us have been somewhat less unsatisfactory than those of the Bassick mine, consisting of two or three visits made in different years when the mine happened to be in active operation, but still have admitted of a very incomplete examination of the deposit, as the workings soon become inaccessible after the ore has been extracted, owing to the crumbling nature of most of the country rock.

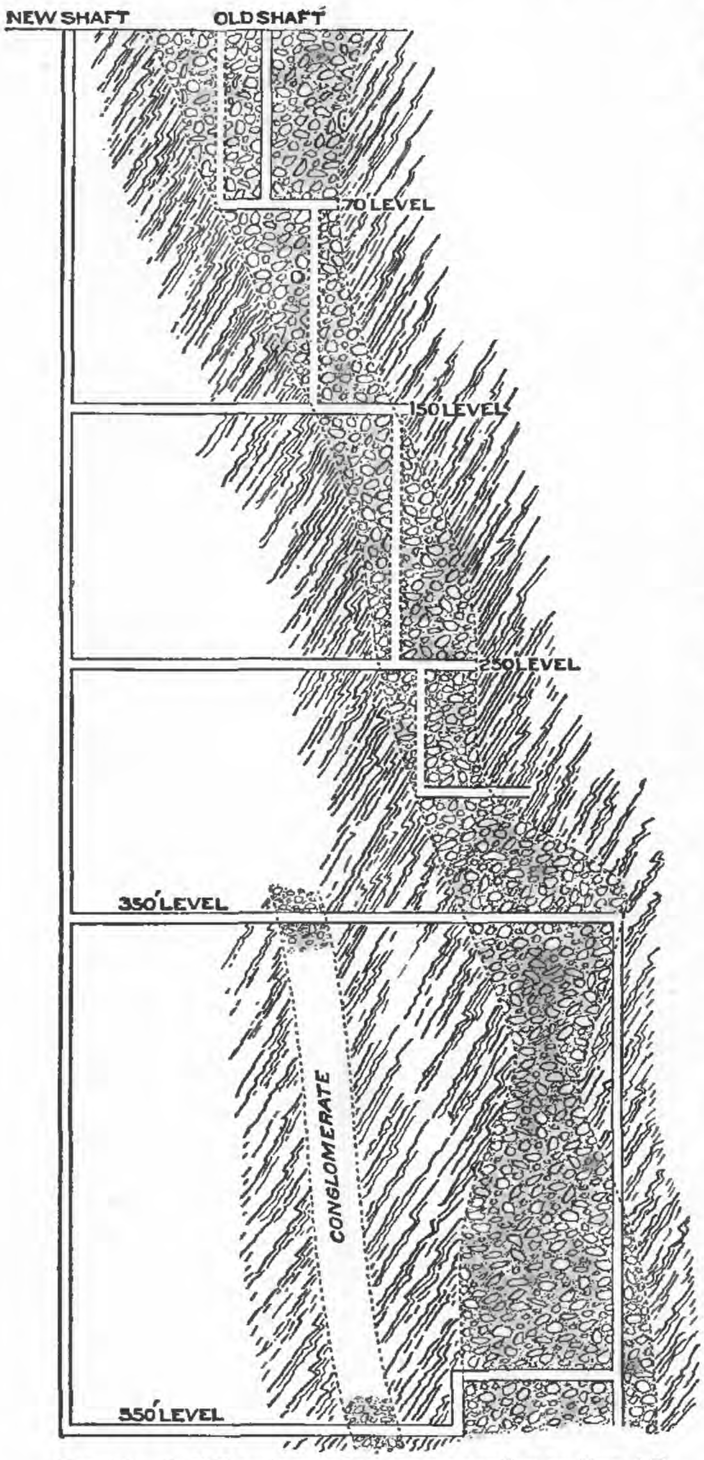

FIG. 42.—Bull-Domingo mine; cross-section on line AB.

A general idea of the form and character of the deposit will be best obtained by reference to the plan and section in figs. 41 and 42 respectively. In fig. 41 is given all the reliable data it has been possible to obtain with regard to the phenomena on the principal levels of the mine, projected on a horizontal plane. The outlines of the ore body there given are those furnished by the mine surveyor, as it was impossible to obtain them by personal observation. They indicate, therefore, rather the limit of pay ore than the actnal geological boundary of the area of ore deposition, but are necessarily within the limits of the latter.

In the section on line AB, fig. 42, is given the form of the pay ore body as constructed from similar data. It has been impossible, however, to determine accurately the form of the conglomerate body which incloses this ore body and contains disseminated through it more or less ore in scattered grains and crystals.

MINERALOGICAL CHARACTER OF THE ORE.

The bowlders or rock fragments which, though they carry no metallic minerals within their mass, constitute the largest and most striking part of the ore body, consist of fragments of the adjoining country rock, gneiss, granite, or syenite—fragments that all were evidently once angular, but which, through some agency, have become more or less rounded. The gneiss, as might be expected from its softer and more easily decomposable character, is more completely rounded than the other rocks and is generally pretty thoroughly decomposed; but even this has sometimes angular outlines on one side. The granite is also pretty well rounded, as a rule, but is less decomposed than the gneissic bowlders. Both gneiss and granite are rich in quartz, and the latter generally resembles the rock of the dike mass of pink granite that outcrops just east of the shaft house. The syenite, on the other hand, which is exactly like the rock of the dike (red, fine grained, and without quartz), is almost invariably angular, only the sharper edges being slightly rounded and the rock entirely unaltered. The bowlders vary in size very greatly—some are several feet in diameter, but as a rule they are from 1 foot down to 2 or 3 inches. The matrix between the bowlders is of the same material as the bowlders themselves, but is very fine grained. It is mostly decomposed and disintegrated gneiss, with occasional pebbles and grains of granite and syenite.

The minerals that have been deposited around these bowlders are usually few in number. They consist of galena generally well crystallized, zincblende of the dark ferriferous variety and usually in fibrous rather than crystalline form. Pyrite is also disseminated in very limited amount through portions of the body. As earthy or gangue minerals are calcite, dolomite, ankerite or siderite, and quartz (usually in the form of chalcedony). The shell formed of part or all of these minerals is generally from a half up to an inch thick. As a rule the shell completely surrounds the bowlder; in other words, there is usually a double band separating two adjoining bowlders, but these are sometimes wanting and the bowlders are in actual contact with each other. Between three or more adjoining bowlders there is generally a small open vug-like space not filled by the bands of vein material.

The order of deposition of these minerals appears to have been as follows: The first band around the bowlder is either galena alone, or more generally galena and zincblende interchangeably, and with no sharp dividing line between them, the galena, however, being crystalline and the zincblende amorphous or with a fibrous structure. Upon this band is sometimes a slight coating of dull, lusterless galena in octahedral crystals. A few specks of pyrite are sometimes associated with these minerals. Outside the metallic bands come the various spars, which always form the interior lining of vugs. The order of deposition of these, as observed in some of the larger vugs, is (1) white dolomite, (2) ankerite or siderite, (3) light-colored calcite, (4) white or yellow chalcedony in botryoidal form.

The silver seems to be mostly in the galena. The coarse-grained galena runs 79 to 82 per cent in lead, and carries about 68 ounces of silver per ton. The fine-grained galena, on the other hand, is considered to contain less of either metal on the average.

FORM OF THE ORE BODY.

From a geological standpoint it is more important to determine the outlines of the zone or channel of conglomerate or breccia, the impregnation of which constitutes the ore body, than those of the ore body itself. As it was only in the pay mineral that the owners of the mine were interested, however, they paid little attention to the extent or form of the barren bowlder mass which surrounded it.

As a matter of observation, it was found that there was no sharp line of division between pay ore and barren bowlder mass, but that the one graded off insensibly into the other. On the other hand, the ore body generally had one, sometimes two or more sharp boundary lines, which were evidently planes of fracture, and which were often accompanied by a change of rock on the other side to granite or syenite, as the case might be. Granite was generally found on the hanging or northeast wall of the ore channel. Syenite, when it was found, was on the west wall, and had nearly the strike of the syenite dike at the surface. Thus on the 150-foot level the ore body appeared to have a rudely elliptical shape, 90 by 40 feet in dimensions, with a wall of granite on the northeast; it passed into solid gneiss on the northwest, while on its southeast side it graded off everywhere into a barren conglomerate.

On the 250-foot level the syenite dike was observed on the northwest side of the ore body, though apparently not in immediate contact with the pay ore. No granite was here detected on the hanging or northeast wall, but a wall was found on the east, running north and south with nearly vertical dip.

At the 550-foot level the ore body lies about 150 feet north of the shaft. On this level the miners thought to have two ore bodies, one east of the other, and each having a longer axis north and south, with a barren zone of bowlder conglomerate between them. Both ore bodies were surrounded by barren conglomerate, except on the north, where there seemed to be a fairly well defined hanging wall. On the west the space between the bowlders was largely occupied by calcite and other spars, but carried no ore. There was the appearance on this side of a wall running north and south, but exploration had not been carried systematically to the limits of the bowlder zone, so that it was impossible to define its shape, and it can only be said that its greatest extent apparently lies in a northwest-southeast direction, as above, and that it appears to have grown larger in depth.

At the angle of the drift connecting the shaft with the ore body a drift runs off to the northwest just before the ore body is reached, which follows a narrow zone of what appears to be a friction breccia, where both walls and rock fragments are much decomposed gneiss; the inclosed fragments are rounded, as if by the disintegrating action of percolating waters, for the matrix is the same material as the bowlders, only a little more disintegrated, and seems to curve around the bowlders as if it had gradually flaked off. This bowlder zone is like that in which the ore body occurs, except that the average size of the bowlders is much less and no granite or syenite fragments were found in it. It is about 10 feet wide, and was followed quite a distance, the exact length of the drift being unknown, as it had caved in. A similar bowlder zone is said to have been cut in the 350-foot level, which could not be examined. It may be on the same fracture plane, or on one parallel with it. The dike of pink granite was also cut in the 550-foot level a short distance from the shaft, and crossing the drift at an acute angle, as shown on the plan (fig. 41).

In a general way the phenomena seem to be on a larger scale at this level than on those above. The bowlders are larger on the average, the scales of mineral thicker, the galena generally of larger grain and in greater proportion as compared with the zincblende, and the vug-like spaces between the bowlders are larger and more frequent.

Among the bowlders no fragments of recent eruptive rock were observed in the mine or ore bins, and, indeed, with the exception of a single pebble of quartz-porphyry that had no mineral scale, no rock other than gneiss, granite, or syenite was observed in the mine at all.

With regard to work done in the mine since the summer of 1890, the writer has been unable to obtain any information. It is his impression that the mine was closed down soon after his visit at that time.

GENESIS OF THE ORE.

The above enumerated facts with regard to this ore deposit, though unfortunately meager and incomplete, are sufficient to show a certain resemblance between it and that of the Bassick mine. It is quite possible, however, that if it had been practicable to study both deposits more extensively, the points of difference would have been found to be more numerous or more pronounced. The striking points of resemblance are, of course, the fact that the ore occupies a nearly vertical chimney-like channel in a conglomerate or breccia mass, and the minerals are deposited in concentric scales around the bowlders or rock fragments.

The points of contrast are: First, that the Bassick ore body occurs not only in the midst of recent igneous rocks, but in what appears to have been the actual vent or channel through which an explosive eruption took place, while the Bull-Domingo ore body is entirely in very ancient rocks, and the nearest known recent igneous rocks are almost a mile away, and their probable vent at double that distance. Second, that while the Bassick deposits are almost exclusively of minerals that might have been deposited from gaseous solutions, those of the Bull-

Domingo are pronouncedly such as must have been formed by aqueous deposition.

The evidences furnished of fracturing and faulting are much more frequent and pronounced in the case of the Bull-Domingo than in the Bassick mine, and although this may result in part from the better opportunities for personal examination afforded in the former case, the fact that walls of solid rock are found within limited distances of its ore body, and the general elongated form indicated for the bowlder or conglomerate zone or chimney, are valid indications of a difference in origin and manner of formation from the Bassick agglomerate. To arrive at a completely satisfactory conclusion with regard to the genesis of the Bull-Domingo bowlder zone, it would have been necessary to have access to a much larger portion of the country rock surrounding the ore shoots than would have been possible even had all the drifts that exist been open to observation.

In the present state of his knowledge, therefore, the conclusions of the writer are, that although craters of explosion are known to exist in which the materials thrown out have in part fallen back and filled up the orifice from which they were ejected—such for instance as the Maare of the Eifel, or, to quote an instance nearer at hand, the Coon Butte in Arizona—the Bull-Domingo ore channel can hardly be considered to have been such a crater of explosion, but was primarily formed by a complicated intersection of a number of fracture planes, which produced a zone of broken country rock, in which the included fragments may have been somewhat rounded by attrition, but whose final rounding was more likely completed by the solvent action of percolating solutions. It seems quite possible that at the time explosive eruptions of igneous rocks were taking place in the adjoining regions, by the force of such explosions heated gases or waters may have been injected through the fissures of the surrounding country rocks, and passing through this broken zone have, partly by attrition and partly by solvent action, rendered more complete the rounding of the rock fragments in this zone, and in that case probably have ejected some of them from near the then existing surface of the ground. As it is probable, however, that several hundred feet of rock material have been eroded off the surface since that time, it is not conceivable to the writer that they could have fallen back freely into such a narrow and intricate channel as this appears to have been. At the best, such a possibility seems at present purely conjectural, and not directly proved by known facts.

The deposition of the ore seems to have been distinctly one made by aqueous solutions, and not to differ essentially, except in the form of the ore channel and the character of its previous filling, from that of the ordinary vein deposit. More or less rounded fragments of country rocks coated with concentric shells of metallic and other vein minerals are known to occur in well-defined fissure veins. Instances are noted in the present paper in the case of the Humboldt vein, but in such cases there is no evidence that the manner of deposition of the mineral has been different from that in other parts of the vein.

In the case of the Bull-Domingo mine, as has already been stated with regard to the Bassick ore body, it is the opinion of the writer that it is quite within the bounds of possibility, and even of probability, that further explorations beyond the line of the present ore chimney, along lines of fracturing and faulting, may disclose other valuable ore bodies whose existence is at present not suspected.

CHAPTER V.

MINES IN RHYOLITE NEAR SILVER CLIFF.

GEOLOGICAL SKETCH.

The rhyolite area near Silver Cliff includes what may be called the Silver Cliff plateau, with Round Mountain and the intervening valley. The plateau is about 2 miles long and 1 mile wide. From its northern part rise the White Hills, which have no special topographic importance, as their highest point is only 400 feet above the northern edge of the rhyolite mass. Round Mountain, on the other hand, is a quite sharply pointed conical hill, so steep-sided as to constitute an important topographic feature, although its elevation above the plains around it is barely 700 feet (see Pl. XXXVI.) The summit of Round Mountain is formed of dense, banded rhyolite, with steep, irregular dip; the southern end is of breccia containing fragments of the banded rock. There are slight exposures of glassy forms of rhyolite on the lower slopes. On the east side of the mountain the Archean rocks extend halfway up its side, and the contact between these and the rhyolite is vertical, or dips steeply to the west. This mountain is supposed to be the vent from which the rhyolite of the plateau was poured out.

The Silver Cliff plateau occupies the site of a former basin, in which at one time there was probably a lake. At the time of the rhyolitic outburst of the Rosita Hills there was a local eruption of the same character in this region, commencing with showers of volcanic ash and of rock fragments, which filled the lake and built up hills about it that have since in great measure been removed by erosion. At present the southern half of the plateau is capped by solid lava to a depth in places of 150 feet. The cliff of blackened rhyolite on the southern edge, which constituted the main discovery of ore, was 30 to 50 feet high. In many places, as in the Vanderbilt mine, the rock is plainly fragmental and stratified, and has a well-defined dip. The contact of Archean and rhyolite along the western border is a gently undulating surface, and in most of the prospect holes the Archean is much broken and resembles a breccia. The northern half of the area is breccia and tuff, except a few dikes of massive rock. At the Songbird and Mountain View (1)[1] mines, and along the western border generally, the gneiss under the rhyolite has been much altered and is locally ore bearing, carrying

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[1] Numbers in parenthesis in the text correspond to those on the geological map, Pl. XXVI, which accompany shafts not indicated by a name.

magnetite, pyrite, and some galena, as in the Immortal and Keystone mines. Near the Sunrise, and along the eastern border as far south as the Vanderbilt, the rock is a finely bedded tuff dipping south and west. The thickness of fragmental material below the highest point of the hills is more than 550 feet. These beds terminate abruptly to the south along an east and west line running near the Vanderbilt, which Mr. Cross thinks may be a fault line.

The massive rock is everywhere characterized by a banded or fluidal structure, and in it topaz and garnet have been found. Under the massive lava on the southern portion of the plateau is pitchstone or glassy rhyolite about 50 feet thick, with about as much more below, containing spherulites, which, when decomposed, form a bowlder zone. These glassy rocks outcrop around the cliff to the south and east, and are found in cellars in the town of Silver Cliff.

THE SILVER CLIFF.

The exact ownership of the various claims which cover the deposits on the cliff overlooking the town of Silver Cliff at the southern edge of the Silver Cliff plateau is not known to the writer. It is understood that the original discoveries of rich surface rock were made on the Racine Boy and Silver Cliff claims. As no defined ore body was ever found at or near the surface, and the pay rock graded off so indefinitely into practically barren rhyolite that those engaged in working it could rarely tell one from the other by simple inspection, the claim lines had no geological significance and no attention was paid to them. Soon after the discovery of the surface ore the Silver Cliff Mining Company, with $10,000,000 nominal capital, was organized in New York, it being then supposed that the supply of ore was unlimited. A 40-stamp dry-crushing amalgamating mill was first erected (1880), and when the grade of the ore had begun to fall off a wet-crushing mill, with the same number of stamps but double the capacity, was planned and erected in the following year. In 1883, when this work was inaugurated, the mills were closed down for want of a sufficient supply of pay ore to keep them running, but a certain amount of ore was being gathered from the open cut on the Racine Boy ground which was hand sorted and shipped away, carrying, as was claimed, an average of 50 to 60 ounces of silver per ton.

At the time of the second visit to the district, in 1887, a new company, known as the Security Company, had taken possession of the Silver Cliff property. They had opened the Silver Cliff quarry more systematically in the endeavor to find an ore body which they could follow in depth, and, having gleaned all the pay ore they could near the surface, had decided to sink a shaft in search of an ore body in depth which their superintendent, Mr. C. H. Johnson, felt confident he could find.

Pl. XXXVII is the reproduction of a photograph of the Security

Company's quarry as it then appeared. The view is taken looking across the Silver Cliff quarry in a northeasterly direction, the top of Round Mountain appearing in the distance on the right of the sky line. The Racine Boy open cut lies beyond the ridge of broken rock to the eastward. The mouth of the main tunnel is in the left-hand corner of the lower floor of the quarry, hidden from view by the ore bins in the foreground. This tunnel was first started in a northwesterly direction, following the main system of joints or fissures which cross the quarry, one of which is marked by the strong shadow immediately above the tunnel mouth. The tunnel later took a nearly northerly direction to connect with the shaft, which it did a little over 300 feet from its mouth and 104 feet below the surface.

After the shaft had been sunk a certain distance there was a reorganization of the company, whose name was changed to the Geyser Mining and Milling Company. The sinking of the shaft, which was started by the former company, has been carried on continuously by the latter company, and at the time of the writer's last visit, in the summer of 1895, it was 2,100 feet deep, and new hoisting machinery of the most complete kind was being put up, capable of sinking the shaft 2,000 feet deeper.

SURFACE DEPOSITS.

SILVER CLIFF QUARRY.

The original outcrop of the ore-bearing rhyolite on the Silver Cliff and Racine Boy claims was apparently nothing more than the ordinary banded rhyolite, blackened by oxides of manganese and iron, extensively cracked and fissured, and carrying little flakes of chloride of silver in the cracks. As far as known, no other metallic minerals were detected, nor was there any definite boundary or regularity of form to the part that constituted the ore. An area several hundred feet in diameter and 30 to 50 feet thick was thus found to be ore bearing. When examined by us in the quarry, the principal set of joints or rock fractures was observed to run nearly northwest and southeast, and it was on these that the most silver was found. On some of these cracks was a considerable coating of clear black manganese oxide; in others, where there was more iron oxide, the coating had a metallic luster, and it was on the latter, according to the observations of the miners who were sorting the ore, that the principal values were found. A set of secondary joints or fractures crossing the main joints nearly at right angles and reaching to the surface could be observed along the benches of the quarry. These were also heavily coated with manganese oxide and carried ore. It was but rarely at this time that the flakes of horn silver could be detected by the naked eye. Our observations indicated that the horn silver was more frequently deposited on small cracks adjoining those filled by iron and manganese oxides, and apparently of later formation. The light-colored mass of the rock had a faint pink

SILVER CLIFF QUARRY.

tinge, and a specimen analyzed contained 0.06 per cent of manganese oxide. It was the experience of the miners that the silver values did not occur outside of the stained zone.

When the ore body was first worked it is said to have contained from 35 to 50 ounces of silver to the ton, but it gradually decreased in value as it was taken at a greater distance from the surface. While the mills were running it is said that the rock was not sorted, but sent in bulk to the crusher. The last mill runs are said to have assayed only about 7 ounces to the ton, and the greater part of this went off in the tailings.

The ore taken from the quarry was sorted, so as to average 50 to 60 ounces to the ton at one time, but this fell off later, and it apparently was so low finally as not to pay for the working.

It has been a cause of much fruitless speculation that the amalgamating mills were so unsuccessful in treating this ore. It is generally conceded that much the larger portion of the silver was carried away in the tailings, which were afterwards profitably concentrated by hand jigs. A sample of these tailings, carefully quartered down, yielded in the laboratory of the Survey 0.13 per cent of sulphur, which is sufficient to combine with the silver contained and form sulphides. It is also said that a small amount of antimony has been found in the ore by those who smelted it.

A specimen of psilomelane from a prospect hole south of Round Mountain was analyzed in the laboratory of the Survey by Mr. L. G. Eakins, with the following results:

II.—*Analysis of psilomelane on rhyolite.*

	Per cent.
SiO_2	2.30
Al_2O_3	1.81
Fe_2O_3	0.34
MnO	5.71
MnO_2	76.18
CoO	Trace.
ZnO	2.80
Sb_2O_3	0.12
CaO (with trace of Sr)	0.83
MgO	0.29
K_2O	3.46
Na_2O (with trace of Li)	0.81
H_2O (includes 1.41 per cent which escapes below 120° C.)	5.35
Total	100.00

If the silver is generally in the form of sulphide, it would naturally be difficult of amalgamation, and the presence of antimony, especially if in combination with it, would heighten that difficulty.

OTHER MINES.

Small amounts of ore were also found near the surface at many other points on the plateau, which, though not comparable in amount to the Silver Cliff body, were sufficient to encourage prospecting to such an extent that over 400 prospect holes were counted there at the time of examination. For the most part they were already abandoned, and there was nothing to show how the ore, if any there was, occurred. Among the more prominent ones, which have actually produced considerable values, may be mentioned:

1. *The Boulder mine*, which is in the partly decomposed zone containing spherulites. (See Cross, Pl. XXVIII.) Here the ore occurs in the matrix surrounding the spherulites, and does not penetrate the latter except along cracks, showing that it is a later impregnation.

2. *The Vanderbilt mine*, which finds its ore in fine-grained white tuff, dipping about 15° southward. The ore occurs along seams or cracks in the rock, stained by manganese, of which the principal seams run N. 35° W. The ore is chloride of silver, with barite (and cerussite, as stated by the owner). A cross fissure running N. 65° W. cuts off the ore on the south. The rock near the surface is the richer. About 15 to 20 feet down it passes into a conglomerate or breccia, in which the fragments are all of rhyolite, except an occasional piece of granite. A specimen of ore, which was white rock with a seam of manganese oxide one-eighth of an inch thick running through it, gave by assay 12 ounces of silver per ton for the whole piece, while the black seam assayed 60 ounces.

3. *The King of the Valley mine*, which lies about 500 yards northwest of the Silver Cliff quarry. Here surface ore assaying 9 ounces of silver to the ton was found adjoining a line of pitchstone, and another of spherulites, which was supposed to be the vein when the claim was located. A shaft sunk later found a body of manganiferous iron oxide, carrying chloride of silver, under compact white rhyolite and surrounded by pitchstone, decomposed to clay and inclosing spherulites. The ore body was a sort of stockwork about 20 feet wide and extending about 72 feet in a northwesterly and southeasterly direction. The average assay of the whole mass was 15 ounces of silver to the ton. These workings were not visited by the writer. The description of the underground working was obtained from the mining engineer who examined it for prospective purchasers. The shaft was sunk over 100 feet, but no ore was found in depth.

4. *Silver Bar (formerly Kate) mine.*—The ore from this mine, which at one time was estimated at 10,000 tons, was taken from between two fault planes running a little west of north and 15 to 20 feet apart. The ore was a breccia, the cement of which was soft and decomposed. The silver occurred as chloride in films and shot-like grains. Manganese was less prominent than in most deposits; barite and fluorite were

occasional vein minerals. The ore was said to average 10 to 11 ounces of silver to the ton, which was enriched by concentration to near 100 ounces for shipment. The ore extended also in thin cracks and seams into the wall rock on either side, but was not worked there, because of the hardness of the rock.

DEEP DEPOSITS OF THE GEYSER MINE.

The only mine workings that have extended to any considerable depth on the plateau, say over 100 feet, are those of the Secnrity-Geyser mine. As far as is known, the ore of all the plateau deposits had given out or been lost trace of within considerably less than 100 feet of the surface. The ore was always chloride of silver where its character could be distinguished. That from the Kate (Silver Bar) claim, worked in early days, is said to have contained some gold also, but this is the only case known, and it has not been verified. It does not seem likely that the silver would be accompanied by gold in one place and free from it in all the others. As will be seen later, of the two shipments to smelters of ore from the bottom of the Geyser shaft, one contained only one-tenth of an ounce of gold per ton, the other but a trace.

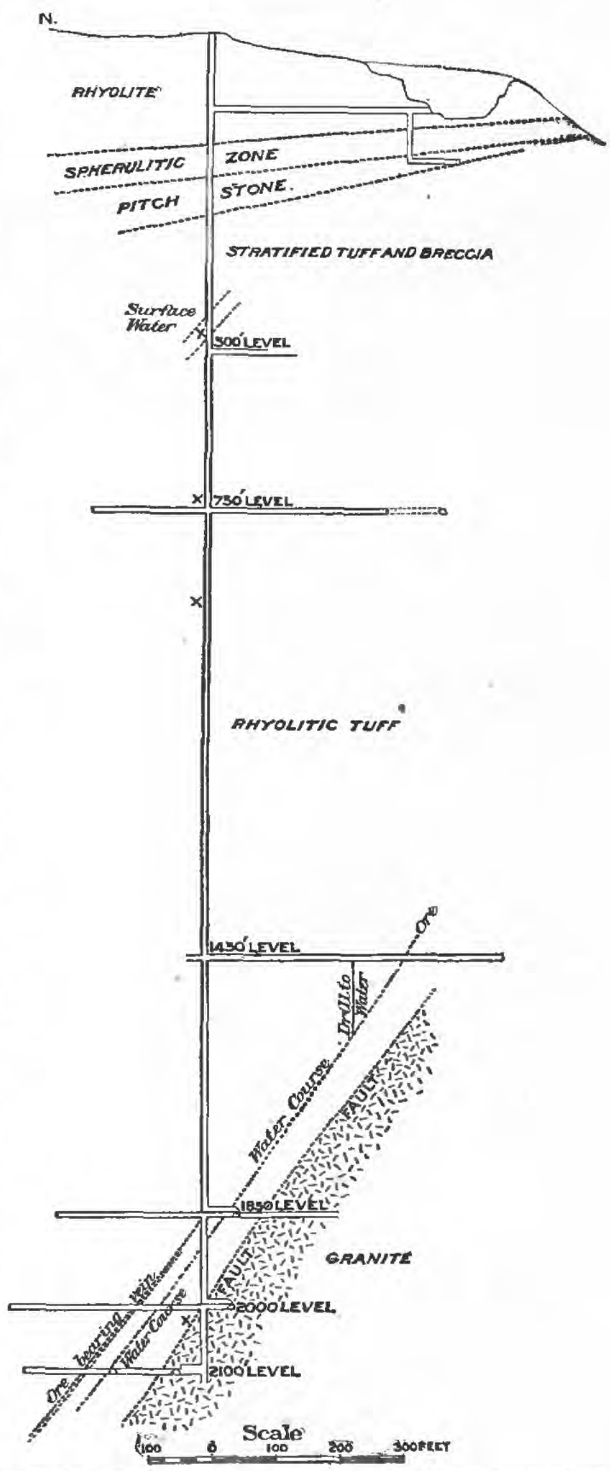

FIG. 43.—Geyser mine; cross-section through shaft on north-south line. Crosses indicate localities where charcoal was found.

It is only through the underground workings of the Geyser shaft, therefore, that it has been possible to obtain any information with regard to the conditions of ore deposition in depth. The data that it has been possible to obtain with regard to them in occasional visits during the past years will therefore be given in considerable detail.

The Geyser shaft, as it is now called, is a thoroughly built 3 compartment shaft, located 350 feet north, a little west, of the mouth of the tunnel or adit leading from the floor of the Silver Cliff quarry, and its collar is 104 feet above that floor. It was originally intended to sink it only 500 feet, it being supposed, from the position of the various contacts of the rhyolite with the underlying Archean that could be observed, that the former was a rather shallow body, and that the underlying granite and gneiss would be reached within that depth. It was later decided to prepare for greater depths, and the hoisting machinery was given greater capacity. The limit of this capacity was reached in the summer of 1894, when a depth of 2,100 feet was attained. Entirely new and heavier machinery, with a capacity of 4,500 feet, was then ordered, which now (May, 1896) is in working order, and sinking has been resumed.

MINE LEVELS.

The first exploring levels or drifts were started at a depth of 500 feet. These were run 500 feet west and 700 feet east; likewise some distance in a southerly direction. At 750 feet levels were run to the east and south, and one branch passed directly under the quarry. Below this, levels were run at 1,450 feet, 1,850 feet, 2,000 feet, and 2,100 feet from the surface, respectively. The general direction of exploration in these levels appears to have been to the west and northwest, but the 1,450-foot level had a drift running southward. Accurate maps of the respective levels could not be obtained, but in a general way it is estimated that the main exploring drifts have a linear extent of about 1½ miles at the different levels, and that about 600,000 square feet of area were more or less thoroughly explored. The section in fig. 43 gives a somewhat diagrammatic representation of the ground explored.

COUNTRY ROCKS.

For the first 150 feet the shaft passed through banded rhyolite. In the tunnel leading to the shaft a narrow zone or band of this rock was found to be changed into a plastic white clay, which was almost pure kaolin. A specimen of this material was analyzed in the laboratory of the Survey, with the following result. An analysis of decomposed pitchstone is appended for comparison.

III, IV.—*Decomposition products of rhyolite.*

	III. Kaolin from Security mine.	IV. Decomposed pitchstone.
Silica	68.16	84.77
Alumina	17.68	8.46
Lime, magnesia, and alkalis (by difference)	1.40	Fe_2O_3 0.52 CaO+MgO 1.10
Water	12.76	4.11
Total	100.00	99.96

A similar band or zone in rhyolite a little south of the base of Round Mountain has been mined and sold to paper manufacturers in Denver, bringing, on account of its remarkable purity and fine grain, a price sufficient to pay for working, in spite of the long haul to the railroad.

Below the solid lava was about 50 feet of pitchstone, then about the same thickness of the bowlder or spherulitic zone. Veins and crystals of calcite were found in the rhyolite under the pitchstone. From 250 feet down to about 1,900 feet the shaft passed through white rhyolitic tuff and breccia, the former often distinctly stratified and generally looking like white sandstone much kaolinized. The breccia varies from fine to coarse, and contains fragments of all the varieties of Archean rocks found in the region, but no eruptive other than rhyolite was observed among the fragments. Some of the Archean fragments are kaolinized and disintegrated; others are quite fresh. The green decomposition product of hornblende and mica was in one place thought to be a copper stain.

Here and there through the tuff, as far as the 2,000 foot level, fragments of charcoal or carbonized wood were observed, the special localities being marked by a cross on the section fig. 43. At 335 feet pieces 2 feet long are said to have been found in the shaft.

The bedding of the tuff was found to be nearly horizontal for the most part. In the shaft a slight dip to the west was noted at times for considerable vertical distances. In the drifts the dip to the west or northwest is more marked in a general way to the southeast of the shaft, and in one place for a short distance this dip was 75°. In the shaft there appears to have been a somewhat irregular alternation of white tuff and breccia. For instance, the former was found continuously from 775 to 905 feet, and from there to 1,000 feet it was mostly breccia, at times with so many large fragments of Archean, up to 2½ feet in diameter, that it was thought the solid formation would soon be reached.

The shaft actually entered the granite and gneiss of the Archean near the 1,850-foot level. Where cut in the drifts below, the contact of rhyolitic tuff or breccia and Archean appears to be on fault planes. The Archean consists of mica and hornblende schists cut by red granite. These rocks are fractured and sheeted in a direction parallel to the ore-bearing veins in the rhyolite, but the actual contact apparently does not conform in every respect to these planes, as might be assumed from the section in fig. 43. The intersections of the contact by drifts are too few to allow of the tracing out of the shape of the Archean wall that incloses the rhyolite. It was noted, however, that the drifts pass out of the Archean into rhyolitic breccia as they go north-northwest or west from the shaft.

In the 2,100-foot level drifts run only north and west, and the contact, as contrasted with that in the level above, has an inclination to the northeast. The contact on this level is not sharp and well defined, but rather a broken zone, first of very coarse fragments of granite and gneiss, then of normal rhyolitic breccia with small fragments of granite and gneiss. The three lower levels have been run 300 to 500 feet north and west in this material, which is sometimes hard and jaspery and of dark red color, but bleaches on exposure to the air. It is traversed by planes of movement, sometimes irregular and curving, but all having a general northwest strike. Beyond one of these planes is a dark bluish rock, supposed by the miners to be limestone because it effervesces freely with acid, but on microscopic examination found to be a decomposed basic eruptive containing considerable calcite.

ORE BODIES.

No defined ore body was found until the 1,850-foot level was reached. Thin films or stains of metallic sulphides, which were said to assay high in silver, occurred occasionally in the shaft and in some of the drifts, lining delicate cracks in the tuff, and sometimes also in the Archean fragments. On the 1,450-foot level, at about 450 feet south of the shaft, a quarter-inch seam of ruby silver and argentite with crystalline calcite is said to have been found in the white tuff, which had a general course north-northwest, and was traced about 50 feet, when it disappeared.

The main ore vein was first found in the 1,850-foot level, about 200 feet northwest of the shaft, as a narrow seam a fraction of an inch wide, with barite and calcite gangue, which widened as it was followed to 4 or 5 inches, mostly of galena, and narrowed again to a mere knife-edge seam in about 150 feet. A few nearly parallel seams containing only calcite and barite were observed near it. This vein was traced by a winze downward, and later cut in the 2,000-foot and 2,100-foot levels, gaining width and richness as it went down. In the former it is quite thin in the middle, and splits into several thin seams at the northwest, which gradually wedge out. On the 2,100-foot level a smaller vein is found about 40 feet northeast of and parallel to the main vein; the latter also splits at the northwest end. The general strike of the vein is N. 37° to 40° W., and it stands nearly vertical, its average dip from the 1,850-foot to the 2,100-foot level being 70° to the northeast.

VEIN MATERIALS.

Although very thin, in no case attaining as much as a foot in width, this vein has been remarkably productive, owing to the richness of the ore and the relatively small proportion of gangue. The principal *metallic minerals are galena, zincblende, chalcopyrite, cupriferous* argentite, tetrahedrite, ruby silver, and possibly stromeyerite or polybasite. Hessite and leaf gold are said to occur, but their presence could not be verified. The galena occurs in fine scaly form rather than in the usual massive crystals. The zincblende is generally of the ferriferous variety known as "black jack" by the miners, and is rather porous. It occurs at times in cup-shaped forms which are lined with fine crystals. It sometimes forms sort of cross courses, or distinct shoots in the vein, which carry from 300 to 400 ounces of silver to the ton, and always a good deal of galena. The chalcopyrite, amorphous and easily disintegrable, occurs mostly in rounded patches distinct from the other minerals and prominent by its dull brass-yellow color. Where the ore occurs in botryoidal form one can distinguish the following succession from the center outward: (1) Barite in tabular crystals; (2) galena (and argentite); (3) copper sulphide; (4) gray copper in crystals; (5) small crystals of chalcopyrite. In certain parts of the vein which consist exclusively of metallic minerals they have a peculiarly fresh look, as if quite recently deposited and not yet completely consolidated. The average composition of the ore is best shown by the following analyses of two carload lots kindly furnished by the Arkansas Valley Smelting Company, of Leadville, to whom they had been sold:

V, VI.—*Ore from Geyser mine.*

	V. Lot No. 1.	VI Lot No 2
Gold	Trace.	([a])
Silver	[b] 1.05	[c] 1.27
Lead	23.80	17.60
Zinc	14.00	11.10
Copper (wet assay)	1.50	2.30
Iron	2.30	2.00
Manganese	1.20	.80
Lime	1.70	....
Sulphur	12.60	9.50
Silica	33.60	46.90
Total	91.75	91.47

[a] 0.10 ounce per ton. [b] 250.42 ounces. [c] 300.28 ounces.

In addition to the above metals there was probably antimony, which has been proved qualitatively in the mineral that was supposed at the mine to be hessite, but is probably either tetrahedrite or polybasite. Barium and alumina probably make up a part of the balance.

Of earthy minerals the most common are barite, calcite, and quartz, the latter generally in the chalcedonic form. Fragments of country rock are found in the vein more or less rounded and changed on the outer part into hornstone-like material, which in turn is coated with galena, barite, etc. Rounded cavities in the vein material are often filled with a white powder, apparently an infiltrated decomposition product of the rhyolitic tuff.

The following are analyses of these two substances, made in the laboratory of the Survey by Mr. W. H. Hillebrand, VII being the hornstone-like alteration product, and VIII the white powder:

VII, VIII.—*Earthy vein materials.*

	VII. Hornstone.	VIII. White powder.
Silica	64.84	*a*86.84
Alumina	16.06	*b*7.44
Ferrous oxide	None.	None.
Manganous oxide	None.	*c*.31
Lime	None.	.89
Magnesia	Trace.	Trace.
Potash	1.37	*d*.25
Soda	.40	
Lithia	Str. trace.	
Barium sulphate	2.00	....
Ignition	*e*7.78	3.89
Total	92.45	99.52

a 2.17 per cent soluble in hot KHO.
b Little F_2O_3 and trace of P_2O_5.
c Possibly Mn_2O_3 or Mn_3O_4.
d Approximate.
e Ignition may represent SO_3, and possibly the loss is also SO_3.

WATERCOURSES.

The rock in this mine has proved unusually dry for the region. In the upper part of the shaft the first considerable flows of water came in at 340, 390, and especially at 420 feet. This water, collected at the 500-foot level, amounted to 250 gallons per minute. This was undoubtedly vadose or surface water, and probably seeped in from the surrounding country. At 945 feet it had decreased to 65 gallons per minute, and below 1,000 feet had practically ceased, the little water that was found being probably leakage along the shaft.

In the 1,450-foot level what may be considered subterranean or deep waters were first struck. They were not very abundant and only slightly charged with gas. At one point on the south drift there was a slight deposit of tufa. A considerable flow was obtained from a vertical drill hole sunk 300 feet downward from this level.

In the 1,850, 2,000, and 2,100 foot levels there are many small watercourses, from which proceed a constant flow of water, not very great in aggregate amount, but highly charged with carbonic acid gas, so that there is a constant hissing, sputtering, and rumbling, and the water is ejected with such force as to go entirely across the drift at some points. These waters apparently ascend along fissures having a general parallelism with the ore-bearing fissure, but no water proceeds from the vein itself. They often come into the drifts through small cracks or cross fissures at an angle with the direction of the main system. As they emerge into the air of the drift they deposit freely a calcareous tufa or sinter on the wall around the crack or orifice out of which they flow. This sinter is sometimes white, sometimes highly iron stained; it has the texture and the peculiar wavy or ripple-marked surface characteristic of the sinters of the Yellowstone Park. In some places it takes a pisolitic form. Again its surface has a shiny glaze. It deposits very rapidly in some places. At one point on the 2,000-foot level, which had been opened only four months, the water issuing from a minute vertical crack on the side of the drift had built out a little ridge of sinter over the crack 1½ inches from its base and less than half an inch thick

The watercourses are most active and abundant near the vein or on the line of its extension. On the 2,000-foot level, where the vein splits to the northwest the water comes in on all sides, and when the shaft was first opened the escape of carbonic acid gas was so abundant at this point that it filled the lower 5 feet of all the drifts on this level and the shaft below the level so that no light would burn, and the miners were obliged to abandon it until a blower could be put in operation to drive the gas out. Even now a light is soon extinguished if put at the bottom of the drift. The water-bearing fissures are mostly in the rhyolitic tuff, but a few are found in the Archean, which shows evidence of faulting within itself in slickensided clay seams and zones of brecciation. The water-bearing fissures decrease in number and in strength of flow as distance from the line of the ore-bearing fissure increases. The abundant escape of gas is the most striking feature of these water courses. Even where no water comes into the drift one can often hear the bubbling and sputtering of the escaping gas in an adjoining fissure.

The temperature could not be accurately determined, but is about the same as that of the air in the drift at the 2,000-foot level, viz, 80° F.

ANALYSES OF SINTERS.

Three typical specimens of sinter from the 2,000-foot level were selected for analysis: one of the perfectly white, with very slight iron stain; one white and brown, both showing the ripple-marked structure well; a third of the pisolitic sinter, strongly iron stained. They were analyzed by Mr. W. F. Hillebrand, with the following results:

IX, X, XI.—*Analyses of sinters from the 2,000-foot level, Geyser mine.*

	IX. White.	X. White and brown.	XI. Pisolitic brown.
Silica and insoluble	0.08	0.10	0.17
CaO	53.11	52.60	52.59
CO_2	42.98	42.57	42.03
Fe_2O_3	.20	1.08	1.82

IX, X, XI.—*Analyses of sinters from the 2,000-foot level, Geyser mine*—Continued.

	IX. White.	X. White and brown.	XI. Pisolitic brown.
Mn_2O_3 (Mn_3O_4?)	[a] .026	[a] .03	Undet.
SrO	.17	.26	.22
MgO	1.50	1.39	1.01
K_2O	03	.03	.04
Na_2O	.17	.16	.09
Li_2O	Trace.	Trace.	Trace.
H_2O below 110° C	.33	.51	.53
H_2O above 110° C	.88	.72	.87
SO_3	.29	.50	.58
P_2O_5	Trace.	Trace.	Trace.
Cl	Faint trace.	Faint trace.	Faint trace.
Total	99.766	99.95	99.95

[a] In IX and X manganese was estimated on 34 grammes in each case. The same also showed minute traces of lead, copper, nickel, cobalt, zinc, alumina, and a doubtful trace of antimony.

On comparing these analyses with those of the waters, which follow, it appears that under the influence of free access of air, with presumably reduced pressure and temperature, the precipitation has been mainly of carbonates of lime, iron, and manganese; of the alkalis, magnesia, and of other metals a relatively small proportion seems to have been precipitated.

ANALYSES OF WATERS.

Carboys of water from the 500-foot level, i. e., surface or vadose waters, and of waters from the 2,000-foot level were collected with great care by the foreman of the mine under the direction of Mr. C. H. Johnson and sent to Washington for analysis. Upon arrival there was found to be considerable sediment in each of the carboys, which had presumably been precipitated during the journey, since they had been filtered through cotton cloth when gathered. Mr. Hillebrand found evidence, however, that the filtering had not been complete, as some splinters of wood were found in the sediment, which casts some doubt on the analysis of the sediment.

In the 42.6 liters of vadose water of which the analysis is given below, there was a deep blackish-brown sediment, containing, however, no organic matter, which, after drying at 110° C., weighed 0.5592 grammes, and gave—

	Grammes.
Ignition	.0642
HCl extract	.1588
Insoluble silica and silicates	.3362
Total	.5592

It was assumed that the silica and silicates must have been mechanically introduced through want of sufficient precautions in filtering at the mine, and this portion of the sediment was not analyzed. Of the sediment in the carboy of deep water the insoluble portion was analyzed, however, with result given in the first column of Table XIII. The filtered vadose water had a slightly alkaline reaction and contained no organic matter. The deep water was more alkaline and contained some organic matter.

XII.—*Vadose water from the Geyser mine, 500-foot level.*

[W. F. Hillebrand, analyst.]

In sediment soluble in HCl.			In filtered water.		Assumed composition before sediment was deposited.
	Amounts found.	*Referred to parts in 1 million of water.*		*Parts in 1 million.*	*Parts in 1 million.*
SiO_2	.0012	SiO_2..Trace.	Cl	7.9	7.9
PbO	.0010	Pb...Trace.	SO_4	43.2	43.2
CuO	.0008	Cu...Trace.	CO_3[a]	108.3	110.5
Fe_2O_3	.0456	Fe 7	K	10.6	10.6
Al_2O_3 P_2O_5	.0365	Al_2O_3 P_2O_5 .8	Na	36.4	36.4
			Li	Trace.	Trace.
Mn_3O_4[b]	.0498	Mn...... .8	Ca	37.3	37.4
ZnO	.0104	Zn...... .2	Mg	12.2	12.25
CaO	.0096	Ca 1	Pb	....	Trace.
MgO	.0039	Mg...... .05	Cu	....	Trace.
CO_2	(c)	CO_3[d]...2.2	Mn	....	0.8
	.1588	4.85	Zn	....	0.2
			Fe	....	0.7
			Al_2O_3 P_2O_5	....	0.8
			SiO_2[e]	25.9	25.9
				281.8	286.65
			Free and semi-combined CO_2	38.8	37.2
				320.6	323.85
			Total CO_2	118.2	....

[a] Calculated.

[b] Assumed condition.

[c] Any traces of CO_2 present have been neglected.

[d] Calculated for the metals as carbonates before deposition.

[e] No tests for other possible constituents were made.

XIII.—*Deep water from the Geyser mine, 2,000-foot level.*

(Spec. grav. at 27° C.=1.0036.)

[W. F. Hillebrand, analyst.]

Composition of sediment (from 43.76 kilogrammes of water).			
Insoluble in dilute HCl; chiefly clayey and feldspathic material; weight dried at 110° C. =5.0134 grammes.		HCl extract.	
	Per cent.	*Amounts found.* *Grammes.*	*Referred to parts in 1 million of water.*
SiO$_2$	54.07	.0667	SiO$_2$. 1.52
Al$_2$O$_3$	29.70	*a*.0461	Al$_2$O$_3$. 1.06
Fe$_2$O$_3$		.2100	Fe ... 3.36
TiO$_2$		....	....
CaO	A little (as, CaFl$_2$?)	2.7921	Ca ... 45.57
MgO	None.	.0778	Mg ... 1.07
K$_2$O	4.40	Not tested for.	....
Na$_2$O	.37		....
SO$_3$	....		....
CO$_2$	....	*b*2.3153	CO$_3$*c* . 76.18
SrO	....	.0440	Sr .... .85
BaO	....	None.	Ba .. None.
Fl	A little.	....	....
PbO	....	0610	Pb ... 1.30
CuO	....	.0011	Cu ... .02
Mn$_3$O$_4$ *d*	....	.0232	Mn .. .38
ZnO	....	.0095	Zn ... .17
Ignition	9.47	(*e*)	(*e*)
	98.01	5.6468	131.48

	Composition of filtered water.	Assumed composition before sediment was deposited.
	Parts in 1 million.	*Parts in 1 million.*
Cl	186.40	186.40
Br. and I.	Traces.	Traces.
SO$_4$	161.70	161.70
PO$_4$	Trace.	Trace.
NO$_3$*f*	1.60	1.60
B$_4$O$_7$	Trace.	Trace.
CO$_3$*g*	1437.26	1513.44
Fl	None.	Trace. *h*
K	198.00	198.00
Na	719.45	719.45
Li	2.85	2.85
Ca	100.84	146.41
Sr	1.10	1.95
Mg	176.60	177.67
Pb	.05	1.35
Cu	Trace.	.02
Mn	.19	.57
Zn	.17	.34
Fe	.14	3.50
Al$_2$O$_3$	None.	*i*1.06
SiO$_2$	22.90	24.42
Organic matter	(*e*)	(*e*)
	3009.25	3140.73
Total CO$_2$.	2472.60	2528.46

---

[a] Perhaps derived from the mechanically included minerals of the sediment; contained a little P$_2$O$_5$.

[b] The sediment was largely incrusted on the glass of the carboy and could only be removed by acid, hence the CO$_2$ was calculated for PbO, ZnO, SrO, CaO, MgO as normal carbonates.

[c] This value includes the CO$_3$ needed by Fe, Mn, and Cu, as well as the metals named in the preceding note.

[d] Assumed condition: perhaps partly as MnCO$_3$.

[e] Organic matter not estimated.

[f] Approximate only, but a maximum.

[g] Calculated for normal carbonates.

[h] The fluorine of the insoluble part of the sediment is probably to be credited to the water.

[i] Possibly from the insoluble sediment.

Hypothetical composition of waters from the Geyser mine.

Elements.	XII. Vadose water from 500-foot level.			XIII. Deep water from 2,000-foot level.		
	Clear (filtered) water	Assumed composition before sediment was precipitated.		Clear (filtered) water.	Assumed composition before sediment was precipitated.	
	Parts in 1 million.	*Parts in 1 million.*	*P. c. of total solids.*	*Parts in 1 million.*	*Parts in 1 million.*	*P. c. of total solids.*
LiCl	....	....	....	17.30	17.30	0.55
KCl	16.60	16.60	5.79	361.34	361.34	11.51
K_2SO_4	4.20	4.20	1.46	19.18	19.18	.61
Na_2SO_4	60.50	60.50	21.11	223.53	223.53	7.12
$NaNO_3$	....	....	....	2.19	2.19	.07
Na_2CO_3	38.70	38.70	13.50	1,489.67	1,489.67	47.43
$MgCO_3$	42.70	42.85	14.95	618.10	621.84	19.80
$CaCO_3$	93.20	93.50	32.62	252.10	366.03	11.65
$SrCO_3$	....	....	....	1.86	3.29	.10
$CuCO_3$	....	Trace.	Trace.	Trace.	.04	Trace.
$PbCO_3$	....	Trace.	Trace.	.06	1.74	.06
$FeCO_3$	....	1.50	.52	.29	7.25	.23
$MnCO_3$	....	1.70	.59	.40	1.19	.04
$ZnCO_3$	....	.40	.14	.33	.66	.02
Al_2O_3 } P_2O_5	......	.80	.28	....	Al_2O_3=1.06	.03
SiO_2	25.90	25.90	9.04	22.90	24.42	.78
	281.80	286.65	100.00	[a]3,009.25	[a]3,140.73	100.00
Free and semicombined CO_2	38.80	37.20	....	[b]1,418.61	[b]1,418.61	....
	320.60	323.85	....	4,427.86	4,559.34	....
Total CO_2	118.20	....	....	[b]2,472.60	[b]2,528.46	....

[a] Also traces of KBr, KI, $Na_2B_4O_7$, $CaFl_2$ and $Ca_3(PO_4)_2$.

[b] These figures are minima of CO_2 for the water as existing in the mine, and are undoubtedly much too low.

DISCUSSION.

There are here presented a remarkably complete series of actual analyses, representing—

1. The average contents of a vein deposit of metallic minerals, rich in silver, lead, copper, and zinc, which was first found at over 1,800 feet below the present surface.

2. The contents of subterranean mine waters taken at 2,000 feet below the surface, and evidently coming from still greater depths, very highly charged with carbonic acid, and carrying small amounts of most of the metals that occur in the deposit; also the sinter deposited by these waters as they issue from the rock into the mine drifts—that is, under ordinary atmospheric pressure.

3. The contents of atmospheric waters coming from the surface that, in their downward course, had traversed rocks similar to those in which the first-named deposit is inclosed and through which it may be assumed that metallic minerals similar to those in the deposit may be sparingly disseminated.

From these analyses it is possible to apply a practical test to some of the assumed theories of ore deposition.

Source of solid constituents in the waters.—In the first place, in comparing the contents of the vadose and deep waters, it is seen that though the latter contain about twenty times as much dissolved matter as the former, the relative proportions of the principal constituents are sufficiently alike to admit of the assumption that they have been derived from a similar source, and this source in the case of the surface waters, which should have been practically pure when they entered the rocks, must have been the material of the various rocks through which they have passed in reaching a depth of 500 feet below the surface. In making this comparison one must bear in mind that the deep waters had already deposited the greater part of their lime as sinter before they were analyzed; hence, while the vadose waters contain three times as much lime as magnesia, in the analysis of the deep waters lime is to magnesia in the proportion of only 4 to 5.

The alkalis are in the same relative proportion in each case, though the aggregate amount of the two constituents is proportionately less in the vadose than deep waters. Iron and manganese are in nearly equal amounts in the vadose waters, the latter slightly predominating, whereas in the deep waters iron is in one hundredfold greater relative amount. This might be explained by the relatively larger amount of manganese oxides present in the surface rocks. It has often been noted by the writer that manganese oxides are generally in much larger proportion in the oxidized portions of ore bodies than below the zone of oxidation, which may be due to their forming less soluble salts in contact with atmospheric agents than do the iron oxides.

The other metals are in such small proportions in either case that one can not reason from their relative amounts, and it is not surprising that most of them could not be detected in the vadose waters.

Such constituents as fluorine, boric and nitric acids, strontium, and barium are characteristic of deep sources, but they also might have been present in the vadose waters without being detected in the small amount of solid constituents available for analysis.

The greatest apparent discrepancy is the tenfold greater proportion of silica in vadose over deep waters, but this might be explained on the ground that in alkaline waters an excess of carbonic acid would tend to throw down the silica in solution.

In the deep waters chlorine and sulphuric acid are in about equal proportions, and carbonic acid is greatly in excess of both combined. In the vadose waters, while carbonic acid is still in excess, sulphuric acid is in relatively greater and chlorine in relatively smaller proportion than in the deep waters. In what manner they would combine with the several bases in either case it is of course impossible to say definitely, and the table headed "Hypothetical composition" gives merely one of the possible methods calculated on the old system that prevailed before it was recognized that the various substances are probably dissociated in dilute solutions.

The deductions that the writer draws from these considerations are:

1. That inasmuch as the surface waters must evidently have derived the substances they contain in solution from the rocks through which they have passed in seeping downward, it is fair to assume that in like manner the deep waters have obtained their constituents, in great part, at any rate, from surrounding rocks, and not necessarily at very great distances from where they now issue, since through higher temperature and greater acid contents they would probably have been more active solvents than the surface waters.

2. On the other hand, the great excess of carbonic acid in these waters, combined with the presence of fluorine, boric acid, and chlorine in considerable amount, point to a source where chemical decomposition is actively going on, which might readily be supposed to be a body of still uncooled igneous rocks which surface waters had reached and from which they were sent back toward the surface again along the present lines of fissuring. Although they contain most of the metals that are found in the vein deposit of the Geyser mine, it is not easy to conceive how the metallic sulphides of that deposit could have been derived from waters of such a chemical composition as these have, and it seems more reasonable to assume that these vein minerals were formed by earlier waters of somewhat different composition, that carried more barium and silica and were characterized by sulphuretted hydrogen rather than by carbonic acid.

3. The conditions here seem to negative the prevalent belief that a decrease of temperature and pressure are the principal determining causes of the precipitation of vein minerals from ascending solutions. In the earlier deposits abundant precipitation ceased before the marked decrease of temperature and pressure that accompanies an approach to the actual rock surface was reached, and in the modern mine openings, where present ascending waters have been artificially cooled and relieved from pressure, the abundant deposit has been, like that of thermal springs at the surface, mainly of carbonate of lime and oxide of iron, and contains only faint traces of the other vein materials that make up the bulk of the neighboring vein deposit.

4. It might be assumed that the surface deposits of chloride of silver and oxides of manganese and iron that are thinly and irregularly disseminated through the rhyolite near the actual surface were precipitated from the carbonated waters at a time when they reached the present surface, the oxides having been originally carbonates, and the

silver chloride deposited as such, and that these deposits are therefore a later phase of ore deposition than the vein minerals. A certain color of probability is lent to this hypothesis by the fact noted by Mr. Johnson, superintendent of the Geyser mine, that there is evidence of an escape of warm air or gas through holes at the surface along a zone about 100 feet wide, running east and west through the Geyser shaft house, which in cold weather is visible as steam. Moreover, fluorite and barite are said to have occurred, associated as gangue minerals with chloride of silver, in the Silver Bar (formerly Kate) mine.

On the other hand, all our evidence goes to show that the chlorides and oxides pass into sulphides at short distances below the surface, and that here, as in other deposits, the chloride of silver is a secondary alteration by atmospheric agents of an original sulphide. It appears more probable, therefore, that all the metallic minerals of the plateau were formed under the same conditions and during the same general phase of ore deposition. That they are so irregularly disseminated is probably due to physical rather than to chemical causes. The rhyolitic tuff which forms the main country rock is so poorly consolidated and of so plastic a nature that in it fracture planes are less continuous and less open than in harder and more rigid rocks. Moreover, the natural planes of division, the bedding planes, are horizontal rather than vertical. Hence there have been no well-defined and continuous water channels traversing the whole thickness of the mass, but the ascending solutions, after leaving the vicinity of the bounding walls of harder Archean rocks, have been obliged to follow devious courses along minute cracks and fissures that were not continuous; thus comparatively small amounts of these solutions have reached the upper lavas, and their load has been deposited as thin films in the joints or minute cracks of the rocks. The fact that at the present time the descending surface waters penetrate the mass to so moderate a depth is an argument in favor of this view.

It is probable that the present vein fissure will soon reach and pass into the Archean wall rock, in which it may widen out. It is very uncertain whether, in this case, the ore will continue to be as rich as it has been, for a change in wall rock is generally accompanied by a change in the character of the ore. These points will soon be settled, however, by actual development, as the workings of the Geyser mine follow the present vein in depth.

CHAPTER VI.

GENERAL CONCLUSIONS.

FORMS OF THE ORE BODIES.

The preceding pages have been devoted mainly to the description of the four principal mines that have been opened in the immediate vicinity of Rosita and Silver Cliff. There are other important deposits within this area and in the surrounding region that have not been mentioned, because owing to the irregular and disconnected manner in which they have been worked it has been impossible to obtain any detailed information with regard to them. With but few exceptions these deposits belong to the type of the Humboldt-Pocahontas vein—that is, they are vein deposits on fault planes in some of the many varieties of igneous rocks that outcrop in the region. They are, in general, rather narrow fissures, which do not bear evidence of having at any time constituted large open spaces, but in which the ore-bearing solutions have deposited their contents by first filling the interstices between the sheets of sheared and banded country rock and afterwards partially replacing these sheets or bands by vein materials. The ore in these cases is generally confined to the fault fissure, and the deposits may be characterized as well-defined vein deposits or true fissure veins.

The Silver Cliff plateau mines show a different type of deposit, but, in the opinion of the writer, the essential differences lie rather in the form of the ore channels than in the character of the ore-bearing solutions. From Mr. Cross's description of the Democrat and Ben Eaton (18) mines in the central rhyolitic area these deposits seem to constitute an intermediate stage between the two types. These mines occur on the south point of Democrat ridge, known as Indian Castle. This is a rounded eruptive channel of rhyolite, in which the rock is massive, brecciated, or spherulitic, as the case may be. There are indications that there have been several eruptions. It has since been much altered, and the alteration products vary from hard quartzite-like material to softer material resulting from the kaolinization of interspherulitic glass. Trachyte dikes run both north-and-south and east-and-west through the mountain, and their decomposition product is usually soft. The ore-bearing fissures run north-and-south with a steep eastern dip through both rhyolite and trachyte. The ore solutions followed these fissures primarily, but found the softened spherulitic glass and certain brecciated zones also very good channels. The ore is now found in these seams or fissures, but all soft kaolinized parts are likely to be impregnated. The main ore body is an oval chimney of varying size in soft matter which is connected with a fissure at tunnel level. From one part, on stoping upward, a soft yellow mud flowed out, which was found to carry 40 ounces of silver and $14 in gold to the ton. For the most part the solid masses of ore are less than an inch thick.

It has already been suggested, in the case of the deposits on the Silver Cliff plateau, that the fact that the surface deposits are no longer in the form of fissure veins, as they are found at the bottom of the Geyser shaft, is due to physical causes which have not admitted of the formation of long continuous water channels along fissures. In this case similar irregularities have been produced by chemical causes, but it has been the physical effect—the production of channels of freer flow through the decomposition of the rock—that has led the ore depositing currents to leave the regular fissures.

The deposits in the Archean rocks on the borders of the eruptive region are likewise unusually irregular in form, and in most of the observed cases this irregularity may be ascribed to a combination of chemical decomposition with dynamic fracturing of the rocks—that is, while the ore channels have been primarily determined by the dynamic movements that produce the ordinary rock fractures, vein fissures, and brecciated zones, on which ore bodies are generally deposited, their course has been varied or they have been given unusual forms as the result of the energetic dissolving or decomposing action of heated solutions that traversed them during the closing phases of volcanic action in the region. This supposes a prolonged alteration and decomposition of the rocks along the water channels before the actual deposition of metallic minerals. In some of the observed cases there are fairly well defined fissure veins in the Archean rocks, but more commonly in this region the ore deposition appears to have taken place along a zone of decomposed rock, which zone was undoubtedly determined in the commencement by dynamic action. The ore deposition along such zones, as might be expected, has been more irregularly spaced and less concentrated than would have been the case in a fissure which had not been thus enlarged by chemical decomposition. The Bull-Domingo ore body is apparently an extreme type of such a form of ore body.

Another type is presented by the body of cerussite at Ilse, on Oak Creek, about 12 miles northeast of the Silver Cliff district. It has no known geological relation to the latter district, but is mentioned here because of its somewhat unique character. As seen in 1887, it was a zone 92 feet wide inclosed between two walls, having a north-and-south trend and a dip of 60° to the west, both of which are probably fault planes. The country rock is granite, and the rock between the walls was probably once the same or a similar rock, now altered beyond recognition, shattered into small lozenge-shaped fragments and stained by iron oxide. Practically the only metallic mineral in the deposit was the white carbonate of lead, or cerussite, which occurred lining the cleavage plane or cracks between the lozenge-shaped fragments of country rock and in some cases as seams or veins a fraction of an inch wide running through the mass or following the foot wall. On the hanging wall was a barren zone 10 to 20 feet wide of greenish clayey material, apparently an alteration product of some gneissic rock. On the foot wall side the rich ore extended to the very wall, and a small amount of cerussite was found impregnating the country rock beyond it.

The ore body as defined at the time of visit had a length and depth of about 300 feet, respectively, with an average thickness of 80 feet. The whole mass as taken out would average 8 per cent of lead, and was concentrated with remarkable ease and thoroughness to a product running over 68 per cent in lead. The ore contained practically no other metal than lead, and there was as yet no evidence that it was originally deposited as sulphide. The mineral deposition was simply the filling of interstitial spaces in a zone of shattered and altered rock, with possibly a certain amount of replacement of the original minerals. It may have been the transposition and concentration of deep-seated deposits of sulphide by carbonated waters, such as are now issuing at the surface in the canyon of Grape Creek 3 or 4 miles to the westward. On the other hand, in the Geyser mine no evidence has been found that the carbonated waters now issuing there are forming such a deposit, or that they are attacking the already deposited sulphides, and nothing analogous to the Ilse deposit has yet been found in the Silver Cliff district.

Whether it be admitted or not that the bowlder-filled channel of the Bull-Domingo represents the neck of an ancient crater of explosion, the Bassick ore body is unique in the evidence it affords of a direct connection with volcanic agencies, and in the determination of its form dynamic agencies have apparently played a very subordinate part.

CRIPPLE CREEK DEPOSITS COMPARED.

It is interesting to contrast the deposits of this region with those of the now famous Cripple Creek district, which lies in a very analogous geological position 40 miles to the northward, and which presents in its geological structure so many points of resemblance. There, as here, the main ore deposition has taken place in and around a central volcanic focus, where a series of comparatively recent igneous rocks have broken through an older series of pre-Cambrian crystalline rocks. There, as here, the principal deposition has taken place along a system of fracture planes traversing both the eruptives and the underlying crystalline complex, and, while not strictly confined to the eruptives, it has, so far as present developments show, been more abundant in the former than in the latter.

In the Cripple Creek region there has been one principal and predominant system of mineralized fractures running about north and south.

In this district a system running north and south or a little west of north is apparently the more frequent, but there are also abundant fractures running east and west, and others quartering between the two. The geological history of this region has been more complicated, there have been a greater number of successive eruptions, and it is probably in consequence of this fact that the fracture systems are more varied and complicated.

Mineralogically the contrast is greater. In Cripple Creek the important metal is gold, which was deposited mainly in the form of telluride, and the prominent earthy mineral associated with it is fluorite. Here gold as telluride occurs in certain parts of the district, and fluorite is sparingly found, but the greater part of the valuable minerals are silver minerals in their usual association with sulphides of lead, zinc, and iron, and with barite as the prominent gangue mineral. They differ from the ordinary deposits of this class mainly by their greater average richness.

SOURCE OF THE METALLIC MINERALS.

While it is possible, by careful study of the geological and mineralogical conditions of a series of ore deposits, to find good and valid reasons why the ore-bearing solutions deposited their load in certain forms and certain localities, and while reasonable deductions may be made as to the probable direction from which these solutions came, the question as to the source from which the solvents derived the materials which they have thus deposited in the form of ore bodies is one that trenches somewhat upon the domain of pure speculation. Yet even here there are many facts of geological observation that have a distinct bearing, one way or the other, upon the various speculative views that have been put forth by geologists.

The general views of the writer upon this question have already been expressed in earlier writings—that the heavy metals have probably been brought up from the interior of the earth within the magmas of igneous rocks, and that by some process of differentiation not yet completely understood, either previous to or during the process of cooling and consolidation, they have concentrated within certain bodies or parts of bodies of eruptive rocks. Further, that ore bodies as found at the present day are the result of a concentration—it may have been many times repeated—of the materials thus brought up, which are in all probability very finely disseminated through the present rock masses or combined in minute amounts in the more common basic minerals. This seems a more rational method, and one more in accordance with modern scientific practice, than to content oneself with assuming simply that the ascending waters came charged with metallic minerals from the bathysphere, meaning thereby a region in the interior of the earth which is richer in heavy metals than any part of the earth's crust that comes under our observation, for this simple assumption affords no explanation why metallic minerals are concentrated in one part of the earth's crust and not in another, and it supposes a free flow of waters at greater depths than in our present state of knowledge of terrestrial physics it is considered possible that channels which would admit of a flow of water through them could remain open.

Furthermore, the writer's hypothesis admits of a practical test, which is impossible in the other case. If the vein materials are found to form a constituent part, even in minute traces, of comparative fresh and unaltered country rocks in a given ore-bearing region, and at such distances from any water channels as to render it improbable that these materials could have been brought in through these channels, it is reasonable to assume that these or similar rocks have been permeated by the waters from which the known ore deposits were precipitated, and that from them they derived their contained vein materials. For this reason a series of careful tests of selected country rocks for possible contents in the precious metals was carried on under the direction of the writer at the laboratory of the Survey in Denver. Since the office at Denver was broken up it has not been possible to continue these tests, owing to want of proper facilities in the Washington laboratory.

Such tests of the rocks from this district as were completed, unfortunately very few in number, are given below.

The five assays for silver were made upon four assay tons each of material, and blank assays of a like amount of the lead flux were simultaneously made, the silver contents of the flux being deducted from that found by the rock assay.

In the case of the black granite from the Blue Mountains, another portion of the rock was pulverized and the constituent minerals were separated by the Sonnstadt solution. The bisilicates in this case were found, as shown below, to contain both silver and lead, but no silver was found in either quartz or feldspar.

Assays of Custer County country rocks for silver.

[L. G. Eakins, analyst.]

Rock.	Locality.	Silver per ton.
		Ounces.
Trachyte	600 feet southwest of Humboldt shaft.	0.007
Do	Summit of Game Ridge	None.
Rosita breccia	South of Game Ridge	None.
Do	do	None.
Fairview diorite	Mount Fairview	.01
Tyndall andesite	Northeast spur of Mount Tyndall.	None.
Rhyolite	Top of Round Mountain	.402
Red granite	Near Haskell's ranch	.005
Black granite	Blue Mountains	.025
Bisilicates of black granite (0.045 per cent lead).		.04

It thus appears that 5 out of 9 of the rocks tested contain appreciable amounts of silver, and that in one of these rocks both silver and lead were found to be in combination with other bases in the bisilicates. It seems, therefore, probable that not only the recent eruptives, but the older granites through which the ascending solutions must have passed, contain enough of the precious metals, and, it may be assumed also, of the other vein materials, to furnish, in the long time that is accorded to the accomplishment of most geological phenomena, sufficient material for the formation of existing ore bodies. The analysis of the vadose waters in the Geyser mine has demonstrated the capability possessed by even cold surface waters of taking up such materials in their passage through the rocks. The subterranean waters that were circulating here at the time of the formation of the ore deposits must have been much more energetic solvents, being heated by contact with the cooling masses of igneous rock and probably deriving a certain amount of active and energetic mineralizing agents, such as fluorine, chlorine, etc., from these igneous masses at time of contact. Hence it is fair to assume that the vein materials in this region were originally derived from both recent and ancient eruptive rocks, a conclusion similar to that arrived at by Mr. Penrose, from his more exhaustive study, for the ore deposits of Cripple Creek.

GEOLOGIC SECTION ALONG THE NEW AND KANAWHA RIVERS IN WEST VIRGINIA.

BY

MARIUS R. CAMPBELL and WALTER C. MENDENHALL.

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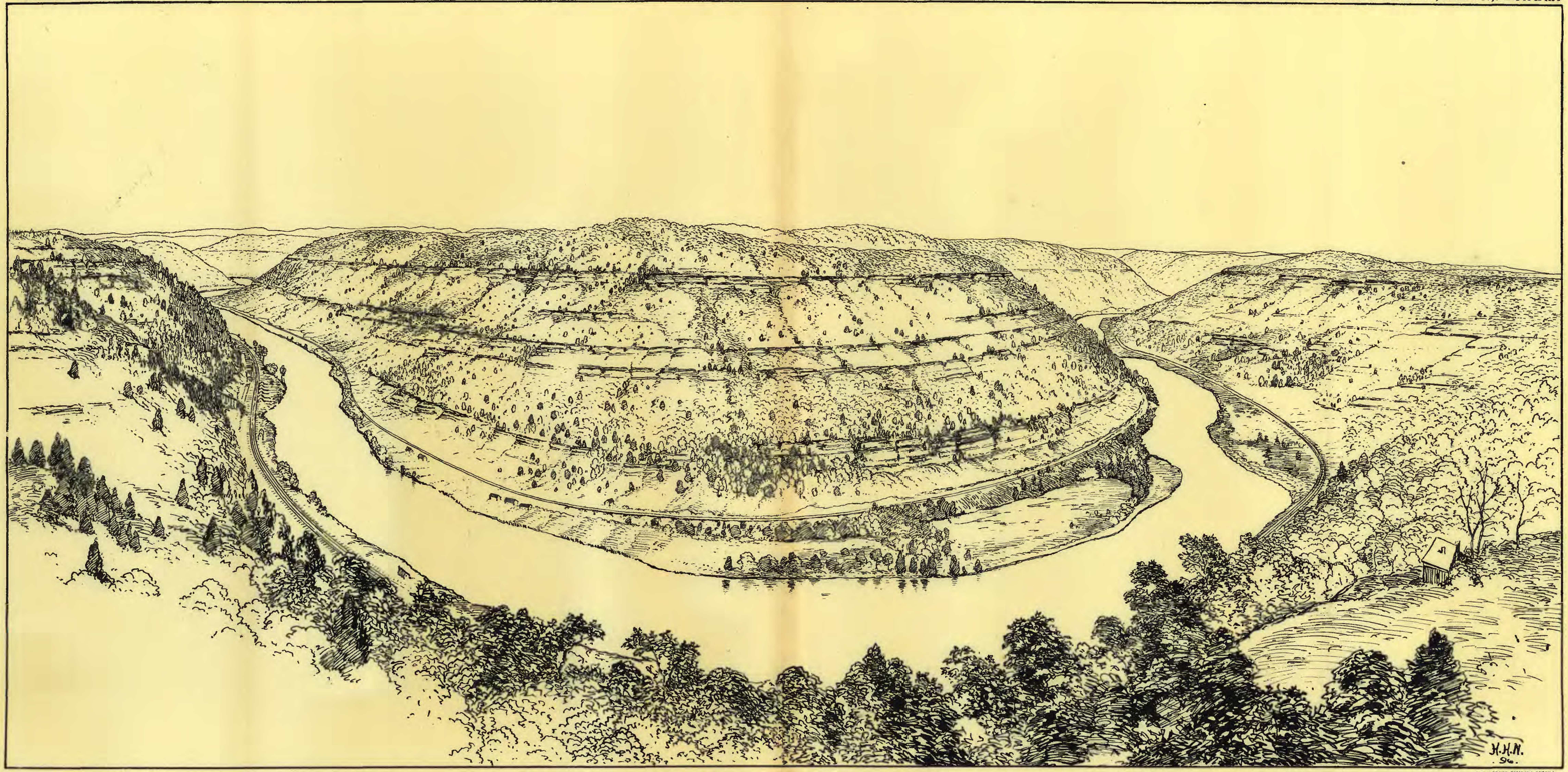

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PANORAMA OF NEW RIVER FROM THE CLIFFS AT FIRE CREEK 1000 FEET ABOVE THE STREAM

GEOLOGIC SECTION ALONG THE NEW AND KANAWHA RIVERS IN WEST VIRGINIA.

By M. R. Campbell and W. C. Mendenhall.

INTRODUCTION.

The Appalachian Coal Field is a structural basin 900 miles in length, extending in a northeast-southwest direction from central Alabama to southern New York. Geologic work in this field was first undertaken in Pennsylvania, and from that State carried westward into Ohio and southward into Virginia, Kentucky, Tennessee, and Alabama.

The result of this work is that the Pennsylvania classification has been extended into the central and southern portions of the basin entirely upon lithologic evidence, it having been assumed that a certain type of rocks invariably marks the basal or "conglomerate" portion of the series, and that another type represents the "Lower Productive Measures;" still another, the "Lower Barren Measures," etc.

While in the main this may be true, recent work has demonstrated that it is not universally so, and hence can not be relied upon for long-distance correlation. Since it is unsafe, in the present condition of our knowledge of the coal-bearing rocks, to attempt correlations of the beds in the center of the basin with those at the extremities, it is well to establish type sections in various portions of the field which can be used as standards in working the surrounding region.

The great expansion of the various members of the series from Pennsylvania southward is another reason for establishing some standard section for the more expanded portion of the measures. The gorge of New River presents such a section, in which the members are so well shown that literally "he who runs may read" the stratigraphic succession.

The greater part of the field work upon which the accompanying section is based was done during the summer of 1895, in connection with the regular areal geologic work on the Raleigh, Kanawha Falls, and Charleston atlas sheets, some additional work being done in the spring of 1896. All of the data appearing upon the general section were obtained from numerous carefully measured sections up the hills, or from well-determined elevations of mines and coal outcrops. For most of the latter class of data the authors are indebted to O. A. Veazey, of Dego, W. Va., but geologic information was also kindly furnished by J. M. Clark, of Kanawha Falls, and by C. C. Lewis, W. O. Reynolds, and J. W. Penhale, of Charleston, W. Va.

The correlation of coal beds from point to point was done mainly upon lithologic and stratigraphic evidence, but in establishing the principal coal horizons the authors have been greatly aided by David White, of the United States Geological Survey, who has made a careful study of the fossil plants in the New River and the Upper Kanawha coal fields, and has generously and unreservedly placed the results of his work at their disposal.

The subject is not a new one, nor are the broader facts here presented new to the students of the region or its literature, but the graphic method of presenting the data in a section which preserves much of the detail, the assembling of the facts of stratigraphic succession in small compass, and the elimination of some errors which later methods and fuller developments have brought to light in the earlier work, make the publication, the authors believe, desirable. The chief end to be gained, however, is the establishment of a standard section for this part of the coal field.

PHYSIOGRAPHY.

One of the principal highways across the rough and broken region known as the Appalachian Coal Field is along the New-Kanawha River in West Virginia. From its source, on the very summit of the great eastward-facing scarp of the Blue Ridge, this stream flows northwestward across the Appalachian Valley and the coal field and discharges its waters into the Ohio River at Point Pleasant, W. Va. Throughout most of its upper course the stream has cut but little below the floor of its old, broad valley, but on approaching the coal field it sinks deeper and deeper into this plain, until it flows in a gorge varying from 1,200 to 1,500 feet in depth. From this maximum, in the vicinity of Hinton, the depth of the gorge gradually diminishes, until at Point Pleasant it does not exceed 400 feet below the highest summits of the neighboring hills.

In order to understand the conditions which have resulted in the corrasion of this great gorge, it is necessary to review, somewhat briefly, the late geologic history of the region, as it is outlined by the physiographic features found in the basins of the New-Kanawha River.

The traveler who now passes along this highway comfortably seated in the railway car sees about him only a rugged gorge with steep hills towering far above, or a narrow valley with softly rounded though steep slopes which lead up to summits of apparently irregular altitudes. He sees an endless profusion of hills, and that is all. He can see nothing of the upland, and so he probably imagines himself passing through the heart of a mountainous country, with rugged summits rising far

NEW RIVER, HAWKS NEST, FROM THE CLIFFS, 500 FEET ABOVE THE STREAM.

NEW RIVER, LOOKING UP FROM THE CLIFFS AT NUTTALL, 1,000 FEET ABOVE THE STREAM.

above the tops of the immediate hills which form the canyon walls. If he is a student of nature and climbs this rugged wall he will probably be surprised to find himself on a remnant of a nearly level plain. He may stand within a few hundred yards of the brink of the New River gorge and yet be unaware that 1,000 feet below him flows a mighty stream in a canyon so narrow that he can cast a pebble from the edge of the cliff almost into the stream below.

Closer investigation shows that this even surface slopes down the stream from an elevation of 2,600 feet above sea level on the southeastern margin of the coal field to 1,000 feet at the other extremity. A still closer examination shows that it is not a continuous surface, but that at a distance from the river it is interrupted by eminences which stand distinctly above it—knobs and ridges rising out of the otherwise regular and continuous plain.

If the traveler is a physiographer, he will see in these features an old, shallow river valley, the home of the ancestor of the present stream. Human history does not reach back to the time when the ancient stream occupied this broad valley, but its history is carved in the hills with as much certainty as if it had been witnessed by man and recorded by his hand. The broader facts are clearly outlined by the physiographic forms, and from them we can read the following succession of events:

Some time during the Tertiary period of geologic history the crust of the earth remained for a long time free from oscillations, at least in the region of the coal field. The surface had previously been raised high above sea level in the interior; consequently, at the beginning of this period of quiescence erosion was very active, the streams rapidly corraded their channels nearly to baselevel, and, as time progressed, these narrow channels were changed by lateral corrasion to broad valleys as low as the bottoms of the original gorges. In this manner the regular surface, which now stands at altitudes varying from 1,000 to 2,600 feet, was produced near the baselevel of erosion.

Some idea of the regularity of this surface can be obtained from Pls. XXXIX-XLII, by supposing the valley now occupied by the stream to be filled to the level of the highlands on either side. That portion represented by Pls. XXXIX and XL would require a filling of more than 1,000 feet, for the observer in neither case is quite as high as the general level of the upland. That portion of the valley shown in Pls. XLI and XLII would require the restoration of at least 800 feet of eroded material before the surface would resemble that which prevailed when the peneplain was formed.

The period of quiescence was not long enough for the entire coal field to be reduced, but broad valleys were cut along the major streams, which then occupied about the same positions as the larger streams of to-day. The topographic features of this region at the close of that interval of uninterrupted erosion were rounded and flowing, consisting of broad plains traversed by sluggish, meandering rivers, and low, rounded hills rising from the general even expanse of the broad valleys. A person unaccustomed to interpreting physiographic features will doubtless find it difficult to believe that much of the coal field which lies within the borders of West Virginia has ever had a low and gently undulating surface, fairly comparable to the coal regions of Illinois and Iowa. The exact time at which this condition prevailed is somewhat uncertain, but the fact that it did prevail in recent geologic epochs is as patent to the physiographer as the present existence of the low plain of the Mississippi Valley is to the ordinary observer.

The termination of this condition of general quiet and uninterrupted erosion probably occurred late in Eocene time by a broad uplift, which may possibly have continued at intervals down to the present. The uplift occurred in the form of an arch with a clearly defined axial line, which passes about through Hinton, W. Va., and the movement raised the broad plain from near sea level to its present altitude of 2,600 feet. South of Hinton the uplift was less pronounced, and the surface was raised to an elevation of only 2,200 feet in the vicinity of Radford, in the valley of the upper New River. Toward the north the descent is much more rapid, the surface reaching 2,000 feet at Fayette, 1,700 feet near Montgomery, 1,100 feet at Charleston, and 1,000 feet near St. Albans.

The first movement of this uplift caused a revival of the drainage, and the streams which had hitherto been too sluggish to corrade their channels now began actively to cut down toward sea level. The main stream carried such a large volume of water that it lowered its channel more rapidly than the upward movement raised it; consequently no ponding ensued, although the surface rose more rapidly along the axial line than farther up the stream.

The result of this continued uplifting of the land and the downward cutting of the streams has been the production of the gorge which affords such a fine highway across a region otherwise difficult of access and presents a magnificent section of the rocks composing the coal-bearing strata of the Appalachian field.

Fontaine recognized the fact that the summits of the hills along New River are flat-topped, and if united would form an extended plain. He did not recognize this surface as a peneplain, but attributed it to the difference in character of the rocks. His description is as follows:[1].

> After climbing the precipitous walls which closely hedge in the river, and which are composed of the conglomerate series, one is surprised to find, on surmounting the topmost rim, that he has only attained the general level of the country. The river is flowing far below him, while around him, and in the distance, rise softly rounded hills, plainly showing that he has passed into a series of rocks of a physical character very different from those he has just left behind.

If a single climb is made, the explanation given by Fontaine seems perfectly adequate. The plain coincides with the upper surface of

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[1] The "Great Conglomerate" on New River, West Virginia, by W. M. Fontaine: Am. Jour. Sci., 3d series, Vol. VII, p. 465.

some heavy bed of sandstone, and the measures above are soft and incapable of producing ridges, unless very favorably situated. Thus if the climb is made at Nuttall the Fayette sandstone forms the floor of the plain, and no hard rocks are to be found above it; if the climb is made at McKendree or Quinnimont, the Raleigh sandstone is found to make an equally good floor, but the isolated hills which rise above it in this vicinity are capped by the Fayette, which is even more massive than the stratum which forms the plain.

If the photographs constituting Pl. XXXIX were perfect, the massive Fayette could be seen in the distance on the right, forming the surface of the peneplain that, at the point of observation, is but little above the cliff of Raleigh sandstone upon which the camera is located. In Pl. XL the observer is standing upon the Fayette ledge above Nuttall, which is but slightly below the general level, and looks southward to the even sky-line that marks the surface of the peneplain in the region about Quinnimont and McKendree. The bed upon which he stands has been eroded in this direction, except on the summit of Big Sewell Mountain, which shows in the distance as a single monadnock rising from the even surface of the plain. Thus the plain does not coincide with the surface of any heavy bed, except for an inconsiderable distance, and if followed far enough it passes from one hard bed to another, holding its own general slope regardless of the outcrops of the hard beds.

The preservation of the peneplain has been almost perfect in this region, because over most of the area it has been protected by the heavy beds of sandstone underlying its surface. As shown in Pls. XXXIX and XL, the peneplain is well preserved to the very edge of the gorge, the river and its large side branches alone breaking the regularity of its surface.

The hard beds of the Pottsville series do not seem to have affected the production of the peneplain, but they have been instrumental in preserving it, and now it constitutes a high plateau, deeply cut by the river, but only slightly dissected by the minor streams.

Along the Kanawha River, owing to the softer character of the rocks, the peneplain was doubtless much more extensive than along New River, but the conditions which allowed of such extensive erosion also favored extensive dissection when the peneplain was uplifted, so that to-day it is difficult to find remnants of the plain which show its originally even surface. All of the ridges are terminated by sharp summits, but when the observer stands upon one of these high points the neighboring summits blend into a regular sky-line which has the appearance of an extensive plain. On account of this great regularity of summits, it has been assumed that they were once points in or near the surface of a peneplain, but they are now wasted to the last degree and may be somewhat below the altitude of the original plain. The immediate valley of the Kanawha River is broader than that of New River, and all of its larger tributaries flow for 10 or 20 miles with easy grades and in broad, flat-bottomed valleys.

From an agricultural standpoint it is unfortunate that the old and broad valley of the Kanawha was destroyed by the great uplift which has been described; but since the rocks composing the Coal Measures of West Virginia do not as a rule produce rich soils, the loss is not so great as it seems at first sight. For the development of its mineral resources, the uplift and subsequent dissection of the country has been most fortunate. It has exposed all of the coal seams, either in the cliffs which border the river valley or in the hill slopes of the numerous tributaries.

GEOLOGIC STRUCTURE.

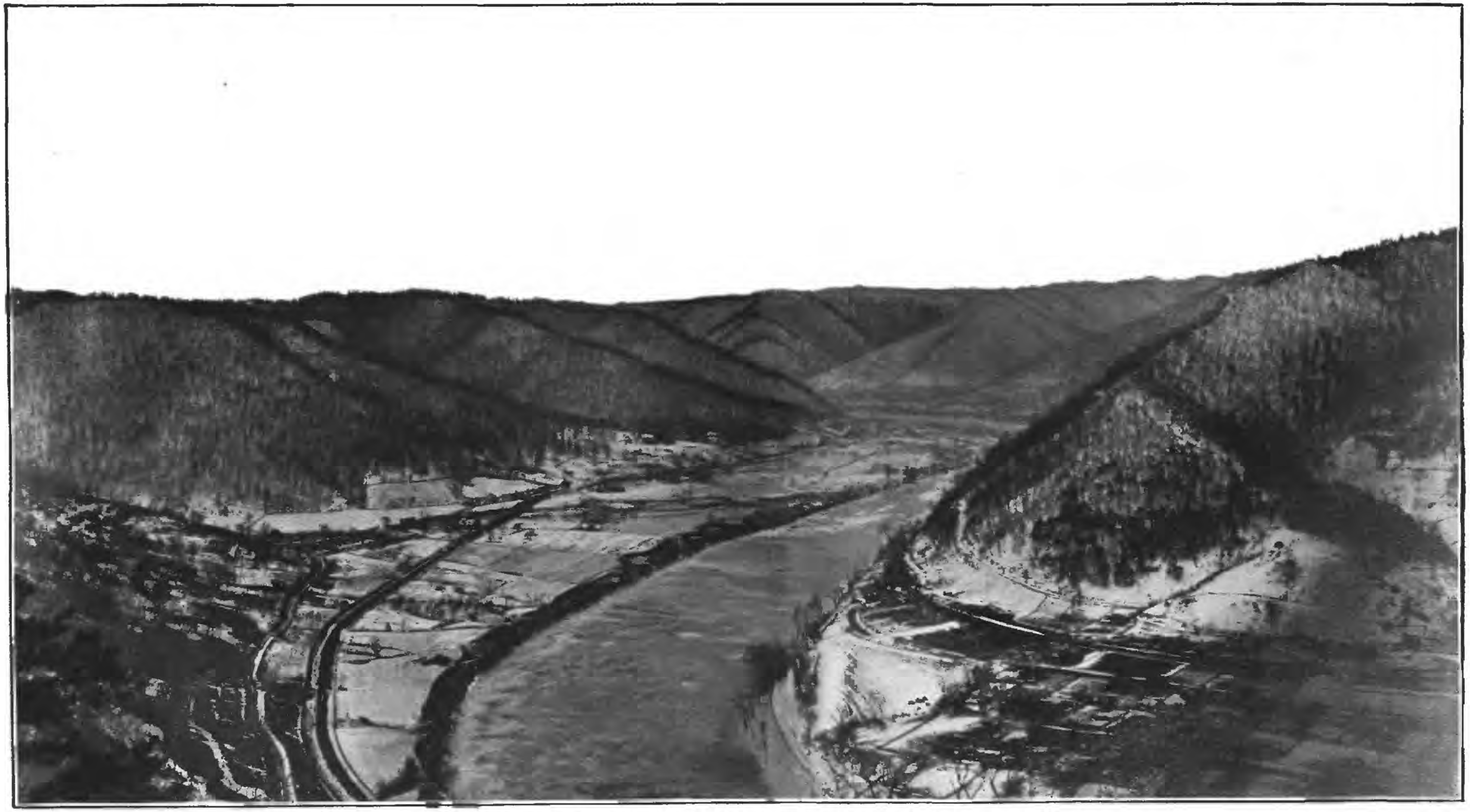
The large geologic section accompanying this paper (Pl. XXXVIII, in pocket) represents the rocks which are exposed along the Chesapeake and Ohio Railway from Hinton to Blackband, a distance of 101.4 miles.

Since the section extends from the southeastern edge of the Appalachian coal basin nearly to the center, the prevailing dips are toward the northwest, or down the river. These dips are generally very light, and in a few cases are even reversed by small folds which cross the line of the section, or by abrupt changes in the direction of flow of the stream.

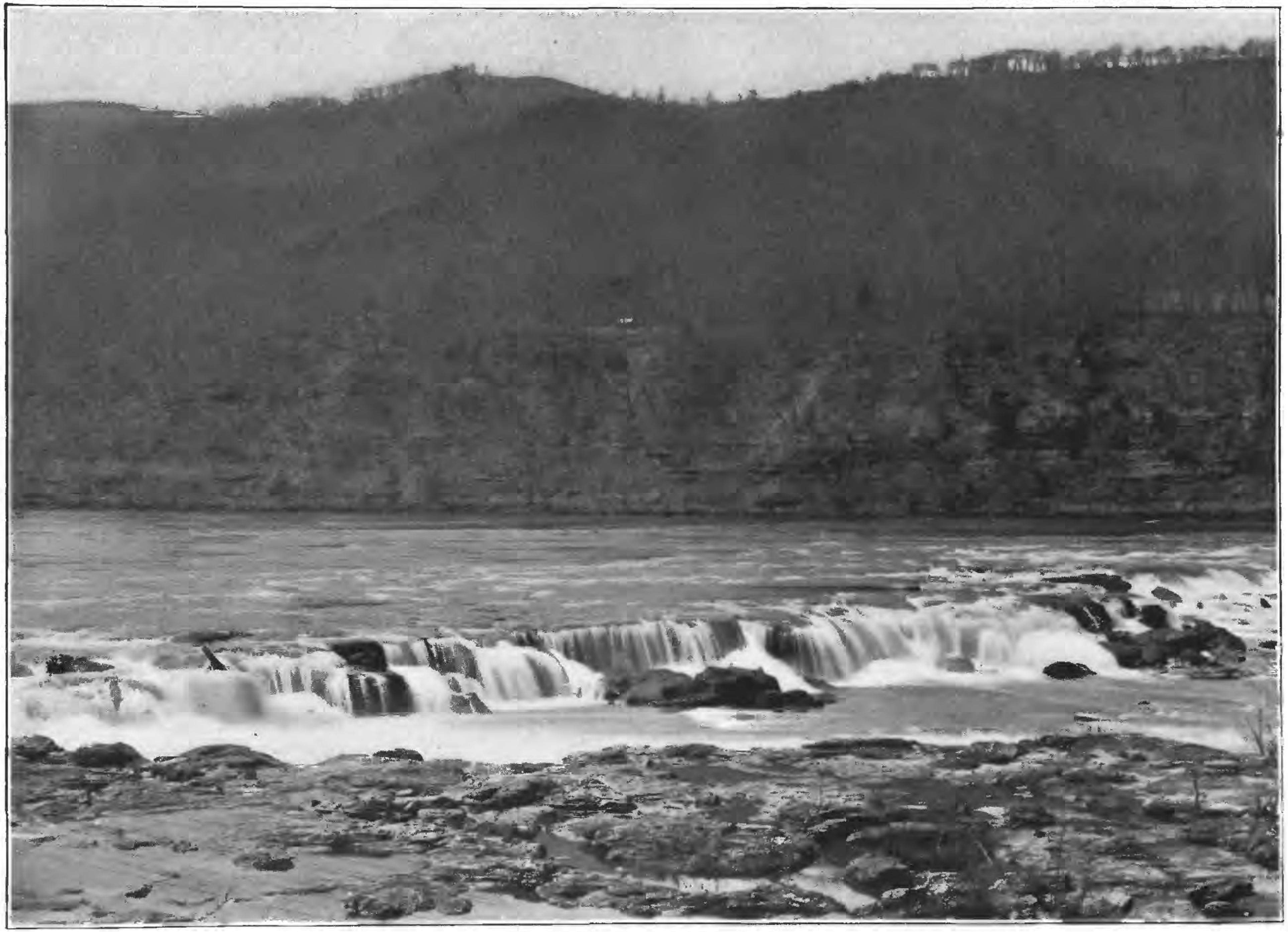
In passing down the river from Hinton the sandstone upon which the town is built can be traced almost continuously to the quarry below the town of Sandstone or New Richmond. This general horizontality is interrupted for a short distance above Brooks by a slight downward bend, which causes this bed to pass below water level for a short distance.

From Sandstone to Prince the general direction of the section is N. 60° W., and the regularity of the descent of the strata is modified only by the sharp bends of the river below the mouth of Mill Creek, a stream entering the river from the south. An admirable view of this downward pitch can be seen in the winter from near Glade Station. To one looking up the stream from this point the hills on the northern side of the river are in full view, and the ledge formed by the Princeton conglomerate can be followed by the eye for a distance of 2 miles. In the interval of 14 miles from Sandstone to Prince the total descent of the strata is 960 feet, or at the rate of 68 feet per mile.

At Prince the direction of the section changes, and the regular dip which prevails from Meadow Creek is changed to a slight rise toward McKendree. This rise is in part due to a low arch in the strata near McKendree, but is also in part only apparent, being the result of a change in direction of the section. In the interval from Prince to McKendree the structure is not easily read from the railroad track, for the Princeton conglomerate disappears, and no bed having a distinctive character is low enough in the cliffs to be readily traced. The Raleigh



KANAWHA RIVER, DEGO, FROM THE CLIFFS OPPOSITE, 800 FEET ABOVE THE STREAM.



NEW RIVER, NEW RICHMOND FALLS.

CLIFF OF HINTON SANDSTONE ON LAUREL CREEK, NEAR SANDSTONE.

sandstone, however, is very massive and easily followed if the observer takes the trouble to climb to the tops of the cliffs, about 1,300 feet above the river. Below Tower X N the strata rise rapidly, so that the Quinnimont coal seam, which at the Royal mine near Prince is at an elevation of 875 feet above grade, reaches 1,040 feet at McKendree. Upon the section the axis of this arch appears to be at Slater, but the continued rise of the strata between McKendree and Slater is probably due to the change in direction of the stream. Since the greatest dip is toward the northwest, every bend of the stream toward the east will be marked by a rise of the beds unless some local structure gives them another inclination.

After passing Alaska the strata dip rapidly, reaching a minimum elevation opposite the mouth of Arbuckle Creek, or at the extreme point of the great northwesterly bend of the river. From Alaska to this point the Quinnimont coal seam descends 690 feet, or at the rate of 153 feet per mile.

At the mouth of Arbuckle Creek the river turns abruptly and pursues an easterly course to Fire Creek, producing another apparent change in the dip of the strata. This change is shown in the bluffs along the river by the increased elevation of the Quinnimont coal, which is mined at a number of places. In the vicinity of Fire Creek the dips are very steep toward the northwest, or directly across the river; consequently the section along the railroad shows the well-known beds at lower elevations than they actually show in the cliffs on the southern side of the river. Thus at Fire Creek the mine is about 710 feet above the grade of the railroad, but the dip brings the coal to 600 feet on the line of the section.

The dip from Alaska to Arbuckle Creek and the rise from that point east to Fire Creek produces on the section a pronounced syncline which is due entirely to the great westerly bend in the river between those points. An air-line section through Fire Creek, Alaska, McKendree, and Prince shows no trace of such a synclinal fold, but shows a gradual descent of the beds from the axis of the arch at McKendree to Fire Creek. It is fortunate that the river has made such a bend in this direction, for it has brought the Quinnimont coal seam much nearer water level and has thus decreased the cost of mining in this section of the river, and has also brought down within reach the Sewell coal seam, which is now mined at Stonecliff, Thurmond, and Beury.

Below Fire Creek the course of New River is regular as far as Hawks Nest, and the strata show a correspondingly regular descent of 900 feet, or at the rate of 64 feet per mile. The descent continues for three-fourths of a mile below Hawks Nest, where it is arrested by a sudden southward bend of the river, which keeps the Raleigh sandstone near water level to Cotton Hill. Since the dip is nearly north, the strata rise even higher at Cotton Hill than above that point, but this is due to the meandering course of the stream and not to local folds.

From Cotton Hill to Gauley Junction the strata have practically the same dip as the railroad grade. The persistence at water level of a heavy conglomerate has, in this interval, given rise to a narrow gorge, the most rugged and picturesque portion of New River. This massive conglomerate disappears below the surface of the stream a short distance below Gauley Junction, and the rapid dip brings the massive Fayette sandstone to the level of the water opposite the mouth of Gauley River, or at the junction of New and Kanawha rivers. Below Kanawha Falls the strata rise slightly, bringing the base of the Fayette sandstone above grade for a short distance, but after passing the southwesternmost point of the bend the strata begin gradually to descend, and the Fayette sandstone passes below water level near the mouth of Armstrong Creek.

From Deepwater to Handley the strata descend at the rate of 97 feet per mile, carrying below the level of the river the top of the Pottsville series and about 400 feet of the base of the Kanawha formation. The northwestward dip is arrested at Handley, and from that point to Winifrede Junction the strata are practically horizontal. A few minor folds cross in this interval, but their effect upon the general horizontality of the bedding is insignificant. Descending the river from Handley, the strata are seen to rise in one of these minor arches, the axis of which is cut by the river at Dego, and is followed by it as far as Crown Hill. Since the river flows along this axis, the rocks show in the hills at the same elevation for a considerable distance, giving to the casual observer the idea that the arch is broad and flat. In point of fact the arch is narrow, and appears broad only because the river follows its axis for a considerable distance. Below Crown Hill the strata descend rapidly for a short distance until they regain the elevations which they held above Dego, and these they then maintain to Winifrede Junction.

Below the last-named point occurs a most pronounced arch, which has been called the Brownstown[1] or Burning Spring anticline. Its axis is located near Brownstown, and the strata at this point are 200 feet higher than the same beds at Winifrede Junction.

From the highest point of this arch the gentle northwestward dip continues regularly down the river to Charleston and Blackband, the end of the section. Below Charleston, however, the westward bend of the river flattens the dip somewhat, so that the beds disappear slowly beneath the grade of the railroad. At Blackband the Charleston sandstone is at railroad grade and the upland is composed of the red shales which form the upper portion of the Carboniferous series.

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[1] Résumé of the work of the U. S. Geological Survey in the Great Kanawha Valley during the summer of 1884, by I. C. White: The Virginias, Vol. VI, 1885, p. 7.

STRATIGRAPHY.

In the following brief description of the strata exposed along the New and Kanawha rivers from Hinton to Charleston, as in the section itself, the authors have applied local names to the subdivisions which they have made. The reasons for adopting this course are as follows:

(1) Many of these subdivisions have no exact equivalents heretofore mapped.

(2) In some instances the probable equivalents are known, but the probability is not deemed sufficiently strong to warrant the adoption of the original name.

(3) The New-Kanawha section should, the authors believe, be made a type section for the middle portion of the Appalachian Coal Field. The development of the series, and the opportunities afforded by the river gorge for studying it, are good enough to warrant the attempt to make it a geologic base whose subdivisions and names may be adopted as far as possible in mapping contiguous areas.

The following table shows the probable equivalence of the formations herein described with those adopted by William B. Rogers in his reports on the geology of Virginia:

Table of probable equivalence of formations.

Campbell and Mendenhall.	Rogers.
Charleston sandstone	XIV. Lower Barren Measures.
Kanawha formation	XIII. Lower Productive Measures.
Fayette sandstone	XII. Conglomerate series.
Sewell formation	
Raleigh sandstone	
Royal formation	
Princeton conglomerate	
Hinton formation	XI. Greenbrier shale.

The carrying of minor correlations from the attenuated western border of the basin through to the eastern side, where a thickness of 1,400 or 1,500 feet is attained in the Pottsville series alone, is attended with so great a probability of error that the authors have not attempted it. It falls within the province of the paleontologist rather than of the stratigrapher, and since connected paleontological work has not yet been done in this region the question of the equivalence of individual beds on both sides of the basin must remain open.

HINTON FORMATION.

The lowest group of rocks exposed in that portion of the New River gorge which lies below Hinton consists of a heterogeneous mass of variegated shales, sandstones of varying character, and impure limestones, ranging in thickness from 1,050 to 1,100 feet. The upper limit of this formation is the base of the Princeton conglomerate, a prominent stratum which shows in outcrop from Hinton nearly to McKendree. Below the latter point the Princeton conglomerate disappears and its horizon can be only approximately located. The lowest bed in this formation is a heavy sandstone, which is a prominent feature along the railroad from Hinton to Sandstone. At the mouth of the Greenbrier River the top of this sandstone is about water level, but northward it rises above the grade of the railroad, and forms cliffs 50 or 60 feet high near the depot at Hinton. The sandstone at this point is rather coarse and medium bedded, having no peculiarities likely to attract especial attention.

It forms almost continuous cliffs along the railroad as far as Tug Creek, at which point it dips below river level, and is not seen again for a distance of 2 miles. Just above Brooks Station it reappears, forming prominent cliffs along the railroad as far as the quarry one-half mile below Sandstone, where it is very massive, and has been extensively used for bridge abutments along the railroad; but a short distance below it loses character, and, almost unnoticed, sinks beneath the bed of the stream.

In the vicinity of Sandstone this bed exhibits some peculiar lithologic characteristics which, when their origin is well understood, may throw some light on the physical conditions under which it was deposited.

One and one-half miles above the station the even-bedded sandstone is suddenly replaced by a peculiar rock which at first sight seems to be a coarse conglomerate—shale pebbles in a matrix of sand. It is very tough and massive, and forms the barrier in New River known as New Richmond Falls. Below the falls the dip changes slightly, bringing the red shale at the base of the bed above water level at the mouth of Laurel Creek, where the photograph reproduced in Pl. XLIV was taken.

The matrix of the deposit is a fine sand, and the seeming pebbles are dark, slightly sandy shale. These pebble-like masses are generally lenticular, but sometimes appear well rounded or subangular; they occasionally show within themselves deposition laminæ, and lie in all positions relative to the bedding, but the position usually assumed is one of approximate parallelism with it. The proportions of sand and shale vary greatly; the beds at some points contain but a few fragments of the latter in an otherwise solid sandstone, and at other points the shale predominates. Scattered through the deposit are unsymmetrical lentils of comparatively pure sandstone, which are frequently cross-bedded, and also frequently show marks of erosion, as though the sandstone had been cut away locally and replaced by the conglomerate-like mass. The origin of this rock is unknown, but it certainly represents changeable conditions, with strong currents or violent wave action. Up the Greenbrier River a change occurs in this bed of sandstone similar to the replacement just described, for at Don, 5 miles above Hinton, where it again rises to railroad grade, it exhibits the same character as at Sandstone.

Above this sandstone is a mass of shales varying in color from dark red or dull green to yellow. They contain bands sufficiently arenaceous to form low cliffs where best exposed, but the usual evidence of the presence of these more sandy portions is a faintly marked bench extending about the hills.

Beds of limestone, usually rich in fossils, occur at several horizons in the shales. They are generally too impure to make lime or to use as a furnace flux, but they add greatly to the fertility of the derived soils. One of the most prominent of these calcareous deposits occurs about 700 feet above Hinton, and is found again in the section below Sandstone at an elevation of 620 feet above grade. At Glade, where the Princeton conglomerate is wanting, a thin limestone occurs near its horizon, and presumably the same bed shows at Alaska, 250 feet above the railroad grade. A third band of limestone shows at railroad level at the mouth of Dowdy Creek, near McKendree, and also at Alaska, 140 feet above the grade of the road. If this correlation between Dowdy Creek and Alaska is correct, there is a noticeable thinning of the strata, for at the former locality the limestone is about 180 feet below the horizon of the Princeton conglomerate, whereas at Alaska it is not over 100 feet below the latter.

The entire series is exposed in the hills from Hinton to Sandstone. Below the latter point the beds decline more rapidly than the stream, and disappear below grade near Beechwood.

PRINCETON CONGLOMERATE.

The Princeton conglomerate, accepted by Fontaine[1] as the base of the "Conglomerate series," is one of the most variable beds of a variable series. It first appears in our section 1,100 feet above railroad grade at Hinton. Its exposure at this point reveals a thickness of from 15 to 20 feet of loosely cemented sand containing many well-rounded quartz pebbles. The shale slopes below its outcrop are not cumbered with blocks, because it is so loose in texture that the fragments broken from it by mechanical agencies quickly fall apart and are rarely found more than 200 or 300 feet below their source. On the crest of the hill below Sandstone, 1,050 feet above the railroad, the stratum is represented by a sandstone which is very hard when unweathered but quickly yields to disintegrating agencies, and contains, so far as seen, no pebbles. Here it is at least 30 feet thick, and perhaps more, for it is poorly exposed and the base was not seen.

The northwesterly dip brings the bed rapidly nearer the grade of the railroad as we continue down the river, and its increasing thickness

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[1] The Conglomerate series of West Virginia, by William M. Fontaine: Am. Jour. Sci., 3d series, Vol. XI, p. 282.

and massiveness, together with its decreased elevation, make it the most conspicuous feature of the river walls from Meadow Creek nearly to Glade. At Meadow Creek this sandstone is 60 feet in thickness and is conglomeratic, and shows 820 feet above the railroad track. At a point 2½ miles below, at an elevation of 600 feet above grade, it has developed into a bed 80 feet in thickness. This is its maximum measure along New River. The observer who climbs to its horizon at Glade can see the massive ledges up and down the river growing thinner as they approach, until they disappear before reaching the position he occupies. Opposite the mouth of Mill Creek the Princeton is 180 feet above grade, but at Quinnimont it has risen to 200 feet, where it is crossed by the road leading from the station to the mine. At this point it is a conglomerate 20 feet in thickness, and lies unconformably upon the shales below. It is absent in the section up Laurel Creek, but comes in again and is present all along the road from Quinnimont to Prince. It thickens rapidly southward from the latter point, presenting a massive cliff 50 feet in thickness below the Royal mine and on Piney Creek. Over the western end of Stretchers Neck tunnel and above Tower XN it shows much diminished in prominence, and is probably represented by a bed 8 or 10 feet in thickness above the mouth of Salt Lick Branch. Farther than this it can not be traced, and, although its horizon does not disappear from view until in the neighborhood of Beechwood, the massive Meadow Creek bed is not found again in the section.

ROYAL FORMATION.

The Royal formation, lying between the Princeton conglomerate and the Raleigh sandstone, shows a gradual decrease in thickness from 1,020 feet, which is its measure between Glade and Meadow Creek, to 960 feet in the vicinity of Prince. Below the latter point its thickness is uncertain, because the Princeton conglomerate is absent from the section, and its horizon can be only approximately determined.

The Royal formation is composite, consisting of two very different classes of rocks. The lower portion, including a thickness of 150 to 200 feet, consists of red and green shales and argillaceous sandstones which, on lithologic grounds, clearly belong to the Hinton formation, or No. XI. The upper portion of the formation is composed of typical coal-bearing strata which, according to David White, contain a true Pottsville flora, and therefore should be classed as a portion of that series.

The natural line of subdivision between the lower Carboniferous and the Pottsville series seems to be at the top of the red shales, but geologists have generally regarded that horizon as variable, and hence unsatisfactory for purposes of correlation. It is true that this horizon does vary, but how the variation occurs is difficult to determine. From the Pocahontas field as a center the horizon between the red shales

GORGE OF NEW RIVER, LOOKING DOWN FROM BLUE HOLE TUNNEL.

below and the Pottsville series above gradually extends upward in the series both toward the northwest and toward the northeast. While it is certain that this horizon does extend diagonally through time and space, it is not known whether the lowest rocks of the Pottsville series in the Pocahontas field are replaced by the red shale and hence were deposited contemporaneously with the deposition of the red shales in other localities, or whether there is a great overlap of the Pottsville series upon the red shales toward the northwest and the northeast. The line of separation between the two formations is not distinct enough to favor the latter hypothesis, but does argue in favor of the former.

Along New River there is no apparent regularity in this line of separation; red shales occur at various horizons in the different sections, and we are forced to the conclusion that the Pottsville coal-bearing strata are gradually replaced by red shales toward the interior of the basin, and hence a formation boundary drawn at this line of contact would not be a true time horizon.

The geologists who have described this section differ considerably in their location of the base of the Coal Measures. Rogers made no definite statement concerning it; Fontaine[1] considers the Princeton conglomerate as the base of his Conglomerate series, and hence he must have included in it from 150 to 200 feet of red shale. I. C. White[2] locates the base of the Pottsville series at the top of the red shales, but he fails to inform us which section is to be established as the type. The practical difficulties in mapping the red shales which lie above the Princeton conglomerate are so great that the present writers have preferred to group them with the coal-bearing rocks above, although they are lithologically different and may belong to another series.

Above this soft basal portion occurs a band of prevailingly arenaceous strata from 400 to 500 feet in thickness. The major portion of this interval is occupied by beds of sandstone, which is usually coarse, heavy-bedded, and frequently conglomeratic. The associated shales are also generally sandy, so that the whole interval is usually marked by a succession of rock faces which give to the gorge an appearance of great ruggedness. It contains no workable coals, although in the shales at several horizons thin seams of coal are visible.

QUINNIMONT-FIRE CREEK COAL.

The remaining beds of this group, up to the Raleigh sandstone, are more argillaceous than those immediately beneath them, and are valuable commercially because they include the horizon of the coal mined at Quinnimont, Prince, Slater, Alaska, Claremont, Beechwood, Dimmock, Rush Run, Red Ash, Central, Fire Creek, and the lower mines

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[1] Loc. cit.

[2] Stratigraphy of the bituminous coal fields of Pennsylvania, Ohio, and West Virginia: Bull. U. S. Geol. Survey No. 65, 1891.

at Stonecliff and Beury. The identity of the seam mined at Quinnimont and Fire Creek was advocated by Edwards[1] in 1891, but was not fully established until David White,[2] in 1894, presented the results of his stratigraphic and paleobotanic work along New River. The occurrence of this coal seam from 250 to 300 feet below the top of the Raleigh sandstone, one of the most valuable bench marks of the series, renders its identification from point to point comparatively certain. The writers were enabled to trace the coal seam from Quinnimont, through the various intermediate points at which it is mined, to Fire Creek, and thus to verify the conclusions of David White that these mines are all in the same horizon.

This coal is too well known to need an extended description, but a few analyses are given to show its general chemical composition:

Analyses of Quinnimont-Fire Creek coal.

Locality.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Coke.
Quinnimont..	0.25	20.98	72.54	6.23	0.89	Lustrous, coherent, brittle.
Slater........	0.40	21.19	75.88	2.53	0.50	Lustrous, coherent.
Alaska	0.41	20.90	69.73	9.01	0.30	Lustrous, hard.
Claremont ...	0.20	22.76	69.99	7.05	0.05	Lustrous, coherent, brittle.
Fire Creek ...	0.73	22.43	75.50	0.80	0.54	

The last analysis is taken from W. S. Edwards's Coals and Cokes of West Virginia; the others are from samples procured by stripping the seam from roof to floor in some heading, or by taking the coal from a number of cars as they come from the mine; hence they are believed to represent closely the commercial product.

The coal is usually firm, bright, of excellent coking quality, and well adapted for steaming purposes, but its great irregularity in thickness is frequently a serious drawback in the commercial development of the seam. It appears to lie in swamps or basins, in which the coal ranges from 3 to 5 feet in thickness, but the swamps are usually surrounded by areas in which it is very much thinner and in places is wanting altogether.

In the original mine at Quinnimont the seam varies from 2 feet to 4 feet 6 inches, but the coal is practically exhausted from the long spur in which the mines are driven, and a new mine has been opened by the same company farther up Laurel Creek. At Prince the thickness of

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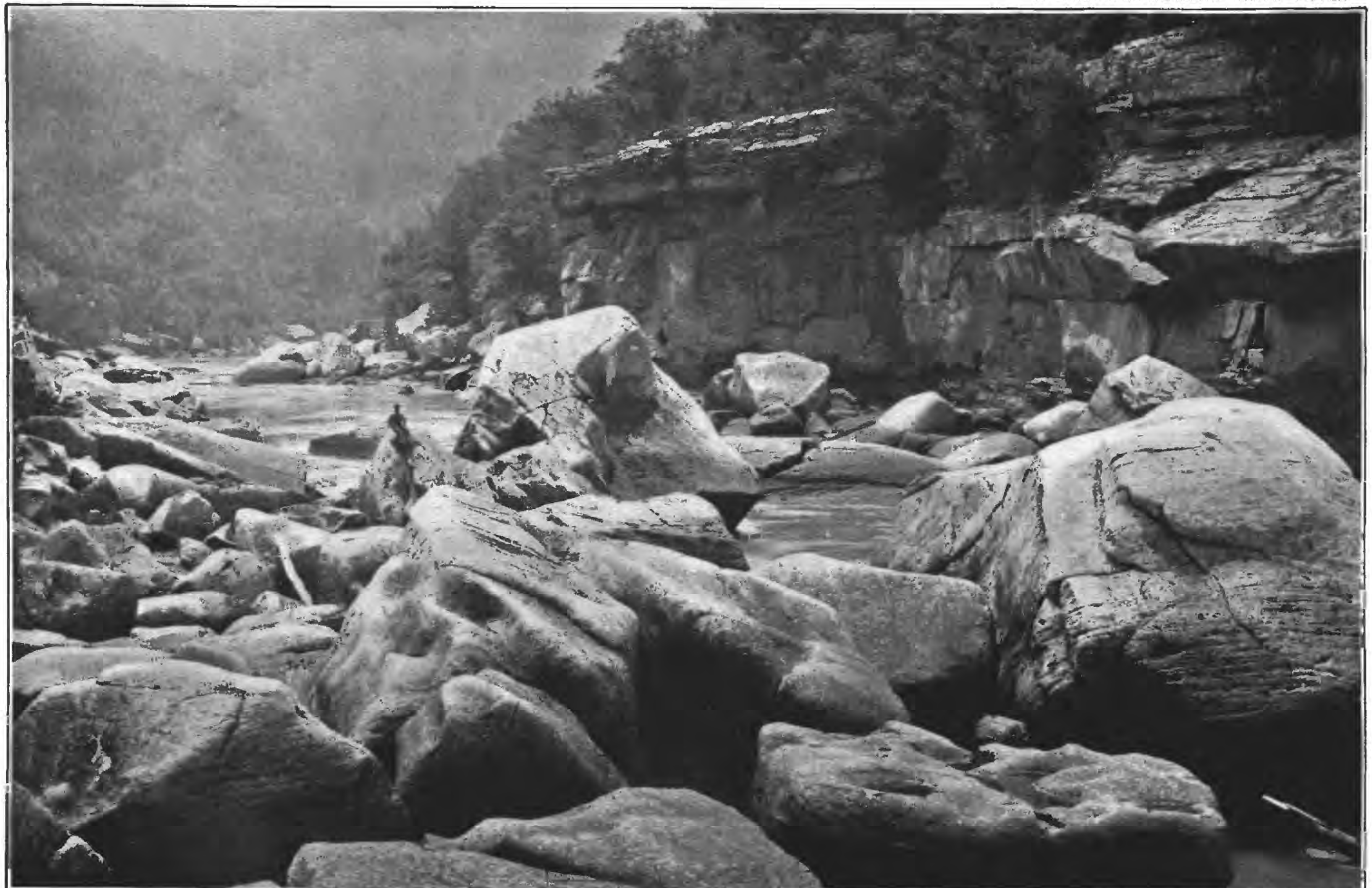
[1] Coals and Cokes of West Virginia, by William S. Edwards, 1892, p. 10.

[2] The Pottsville series along New River, West Virginia: Bull. Geol. Soc. Am., Vol. VI, 1895, pp. 305–320.



CONGLOMERATE BOWLDERS IN NEW RIVER NEAR BLUE HOLE TUNNEL.

the seam runs from 3 feet 6 inches to 4 feet. At McKendree a mine was opened and an incline built from the mine to the railroad, but the seam was found to be only about 18 inches thick and the work was abandoned. At Slater it was found to be too irregular to work profitably, and new mines have been opened farther up Slater Creek, where the seam varies from 2 to 4 feet. At Alaska it runs from 4 to 6 feet, with a heavy band of sulphur at the top, which has to be separated. On the pathway leading up to the Thurmond mine an old opening shows 3 feet 6 inches of coal. This swells eastward, as reported, to 5 feet 8 inches on Rush Creek, a short distance from the former opening. At both the Rush Run and Red Ash mines it varies greatly in thickness. The maximum measure is about 5 feet in the center of the irregular swamps, but these swamps are usually bordered by areas in which it is very thin, sometimes pinching out entirely. At Fire Creek it varies from 3 to 5 feet in thickness, but toward the east and north it becomes so poor in quality and the seam so thin that it is not mined below the last-named point.

The shale forming the roof of this seam is but sparingly fossiliferous. The plant remains which occur in it are usually fragmental and give indications of having been floated to their present resting place. The sandy character of the roof shale would also suggest that the material which buried the old swamp was carried and sorted by rather strong currents which may have been instrumental in cutting away the carbonaceous matter composing the coal seam.

The interval from the coal to the base of the Raleigh sandstone is often obscured by débris, and is therefore somewhat uncertain, but it appears to vary from 170 to 250 feet, the greater interval being found near the upper end of the section and the lesser at Thurmond and Beury. The Fire Creek measure is 240 feet, but corrections for dip will lessen this slightly.

In this interval there is at least one heavy sandstone which belongs about 50 or 60 feet below the base of the Raleigh. It is seen in unusual development along the river from Caperton to Fayette, where it is a heavy-bedded conglomerate, and, though thinner, quite as prominent as the Raleigh, because of its massiveness. This character is not observed for any great distance above Caperton, although a sandstone is usually present at that horizon. The sandstone immediately over the coal sometimes becomes prominent, as at Stonecliff, Beury, and East Sewell, although usually thin-bedded and insignificant. At Quinnimont this part of the section appears soft and shaly. Taken as a whole, the interval above the coal, while having no striking lithologic characteristics, is predominantly arenaceous.

RALEIGH SANDSTONE.

This stratum is one of the most persistent and best-marked beds of the Pottsville series in southern West Virginia. It is the conglomerate bed at the top of the section exposed on the road from Prince to Raleigh, which has been described by Fontaine[1] as follows:

> No. 21 [Raleigh] of the Conglomerate series is the only persistent member. As it is found everywhere throughout the Appalachian Coal Field, being in many places the sole representative of the series, and as it is always at a uniform distance below the lowest workable coal seam of the Lower Productive coal, it would seem to be entitled to be called, as it has been, "The Conglomerate of the Coal Measures."

Fontaine associated this bed with the one which caps the canyon wall at Nuttall, and so supposed that he was describing the uppermost member (Fayette) of the Pottsville series. His description of its persistence is in a measure correct, since it has been traced continuously by the writers from Tug River and the Great Flat Top Mountain in the Pocahontas field, through Wyoming and Raleigh counties, to New River, and along this stream from Glade, where it first appears in the hills back from the river, to Cotton Hill, where its horizon disappears from view beneath the bed of the stream. Throughout this distance, although varying considerably in thickness and physical character, it continues sufficiently heavy to exert a marked effect upon the topography, and to enable the geologist to follow it with certainty.

Very often it is a conglomerate, and, owing perhaps partly to this fact, it was mistaken by some of the earlier geologists for the heavier bed 400 or 500 feet higher in the series which separates the Pottsville series from the Kanawha formation above. For 20 miles along the river above Fire Creek it caps the brink of the gorge, and the view in Pl. XXXIX is taken from a projecting point over the Fire Creek mine. The upper and more prominent ledge on the opposite side of the river is composed of this sandstone, which, were the picture perfect, could be followed by the eye down the river to the right until it passes beneath the massive cliff of the Fayette below Caperton. At Prince, Quinnimont, Piney Creek, and Thurmond it carries quartz pebbles, and between Cotton Hill and Hawks Nest, where it skirts the river a few feet above low water, it is again conglomeratic. The pebbles are usually small, but at Cotton Hill they are large, some of them being 2 inches in diameter. In thickness it varies from 40 to 100 feet, and in character from a massive pebbly rock to a series of flaggy sandstones. Its recognition along the river and in the interior will be of great advantage to engineers and prospectors, because of its constancy and the approximately regular interval separating it from the coals above and below.

SEWELL FORMATION.

The body of shales and sandstones immediately overlying the Raleigh and extending from it up to the Fayette is called the Sewell formation, from the town of the same name on New River at which the coal seam

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[1] Conglomerate series of West Virginia, by W. M. Fontaine: Am. Jour. Sci., Vol. XI, April, 1876, p. 281.

GAULEY JUNCTION.

occurring in this formation was early mined. In Garden Ground Mountain, across the river from McKendree, it first makes its appearance in the river section, and continues above water level to Gauley, where the base of the Fayette dips to the stream.

In passing down the river the first complete section of the Sewell formation is exposed above the mine at Nuttall. At this point the whole of the formation is decidedly arenaceous, but there are only two sandstones heavy enough to produce ledges upon the slopes. The major portion is sandy, but thin-bedded, and gives indications of rapid deposition, probably along the margins of shallow waters where conditions were extremely variable. From Nuttall to Gauley, where this formation passes below the bed of New River, hardly two sections are found to agree in the number and thickness of the sandstone beds in this interval. Thus the Nuttall section shows but two small beds, 150 and 210 feet, respectively, above the top of the Raleigh. At Fayette the section above the mine shows two sandstones which resemble the two at Nuttall, except that they are much thicker, the lower measuring 70 and the upper 60 feet in thickness. The Elmo section is much more sandy, but since the exposures are not good it is impossible to tell the number of beds or their full thickness. At Gaymont the lower bed is present 100 feet above the Raleigh, but the strata above this to the base of the Fayette are almost entirely concealed. At Hawks Nest a similar condition prevails, but the lower bed is here very massive, though of uncertain thickness. A mile below Hawks Nest a fine section is exposed in the cliffs on the eastern side of the river. At this point there are but two sandstone beds in the Sewell formation. The lower bed is only 25 feet thick, but it is very massive and makes a prominent line of cliffs 80 feet above the Raleigh sandstone, which is at water level. The upper bed is 180 feet above the Raleigh and is about 50 feet in thickness.

The lower massive bed remains at a uniform distance above the Raleigh and maintains a constant thickness of from 25 to 40 feet as far down as Cotton Hill. Below this point, about one-half mile, it suddenly swells in thickness to at least 100 feet and becomes coarsely conglomeratic. Its base appears to remain parallel with the top of the Raleigh as far as the latter can be observed, with a constant interval of shale 90 feet in thickness between them. The base dips below the bed of the stream, but the top remains fairly constant at from 40 to 50 feet above the grade of the railroad, throughout the interval from Cotton Hill to Gauley Junction. This is the bed which forms the canyon of New River shown on Pl. XLV, and which gives to it a rugged picturesqueness not found along any other portion of the river's course. All through this part of the gorge it forms the immediate banks of the stream, and huge blocks from it obstruct the channel. Pl. XLVI is a photograph of a group of these immense blocks which have collected in the river above Blue Hole tunnel.

At Gauley Junction this massive conglomerate dips rapidly to water level and it is exposed at low water over a wide area in the bed of the stream. Pl. XLVII shows a portion of this broad rock floor, through which the river has ground out a passageway 90 feet in width. Through this narrow opening in an ordinary stage of water the whole of the drainage of New River from the far-off summits of the Blue Ridge must pass. For thickness and massiveness it is equal to the lower and heavier member of the Fayette in its best development, and might be easily mistaken for it.

The thickness of the Sewell formation varies greatly from Cotton Hill to Caperton, the distance in which its full thickness is present in the walls of the canyon; and still more does it vary in the region between New and Guyandot rivers. At Cotton Hill, where its base passes below the level of the stream, its thickness is but 280 feet; at Gaymont this interval is 320 feet; at Fayette, 370 feet; and at Caperton, 500 feet. At the last-named point the Fayette recedes from the brow of the hills facing New River, and the thickness of the underlying formation is difficult to compute. It is still more complicated in the western part of Raleigh County by the occurrence of two beds of massive conglomerate, each of which completely overshadows the dwarfed representative of the Nuttall cliff. The probabilities are that in this region the Sewell formation is about 650 feet in thickness.

SEWELL COAL.

About 70 feet above the base of the Sewell formation occurs one of the most important coal seams in the Pottsville series on New River. The following analyses of the commercial product will illustrate the character of this coal:

Analyses of Sewell coal.

Locality.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.
East Sewell	0.77	26.55	70.39	2.28	0.67
Keeney Creek	0.91	26.11	70.79	2.19	0.29
Fayette	0.51	26.64	68.94	3.91	0.73

As shown by the analyses, it is not quite so high in fixed corbon as the Quinnimont coal, but the fairly constant thickness which it maintains and its wide distribution make it of greater regional importance than the lower seam.

This seam was first opened at Nuttall about the close of the year 1873, and a little later operations were begun at Sewell. Now it is mined at Stonecliff, Thurmond, Beury, East Sewell, Sewell, Caperton, Nuttall, Fayette, Elmo, Sunnyside, and Gaymont, besides on Keeney Creek at Clifftop and on Dunloop Creek. The original mine at

FAYETTE SANDSTONE CLIFFS, LOOKING DOWN FROM NUTTALL.

Sewell was on the east side of the river, but the strong dip soon carried the seam above the tops of the hills; the coal was quickly exhausted and the mine abandoned. The present mines at Sewell are on the west side, where the seam is low enough in the hills to have plenty of cover, but the mines are driven in on the dip, which makes the work expensive.

The Sewell seam holds a fairly regular thickness over a large area on New River. Its outcrop is limited on the southeast by the line along which it cuts the general level of the peneplain. Although it no doubt originally extended farther in this direction, all of that portion which was above the level of the peneplain was eroded. Toward the northwest it thins gradually, and disappears before its horizon passes below water level at Cotton Hill. In the high land which lies well back from the river in the bend between Sewell and Meadow Creek the Sewell coal has been opened in a number of places, but it is thin and poor. Farther west, however, in the high land opposite McKendree, it shows 4 feet in thickness, and on the head waters of Loop Creek it varies from 5 to 6 feet. In passing eastward from Thurmond it averages about as follows: Beury, 3 feet 6 inches to 4 feet 6 inches; Keeney Creek, 3 feet 5 inches; Nuttall, 3 feet 6 inches; Elmo, 3 feet; Sunnyside, 3 feet; Gaymont, 2 feet 10 inches; and Hawks Nest, 2 feet 6 inches.

FAYETTE SANDSTONE.

In passing down the river from Fire Creek the Raleigh sandstone which crowns the bluff 1,000 feet above the stream is seen to dip lower and lower in the hills, whose summits become somewhat rounded because of the presence of the soft shales and thin sandstones of the Sewell formation. No rocks higher in the series are to be seen until a view is obtained of the high land back of the West Caperton mine, where, 500 feet above the Raleigh, is a rather inconspicuous cliff 30 feet in height. This ledge dips rapidly, and in the bend of the river below Caperton swings into the immediate front of the bluff, where it presents an unbroken wall 100 feet in height.

It reaches its greatest development at Nuttall, where it is particularly massive, being practically without bedding planes, and 110 feet thick.

Pl. XLVIII is a photograph of the hill slope crowned by this massive conglomerate as it appears from Nuttall looking down the railroad track. At many points the shales underneath the ledge are worn back under the outer margin of the cliff, allowing large masses to project unsupported. In time these become separated from the main body and commence their journey to the stream channel below. Thus the face of the cliff is almost always kept vertical and in many places overhanging. These rock faces are always impressive, but never more so than when one stands at their base and looks at some proiectjng point, as shown in Pl. XLIX. The size of the blocks which break from this face is sometimes enormous, and the walls of the gorge are lined by immense bowlders which seem to be ready at any moment to plunge to the bottom and crush everything in their way. The little mining hamlet of Nuttall is located on one of the most rugged of these talus slopes; the miners' cabins are clustered about among the immense blocks, and are dwarfed into insignificance by their mammoth proportions. Each little depression is filled with a stream of débris, which, as it reaches the river, partially dams the current, producing the rapids of which this part of the river is an endless succession.

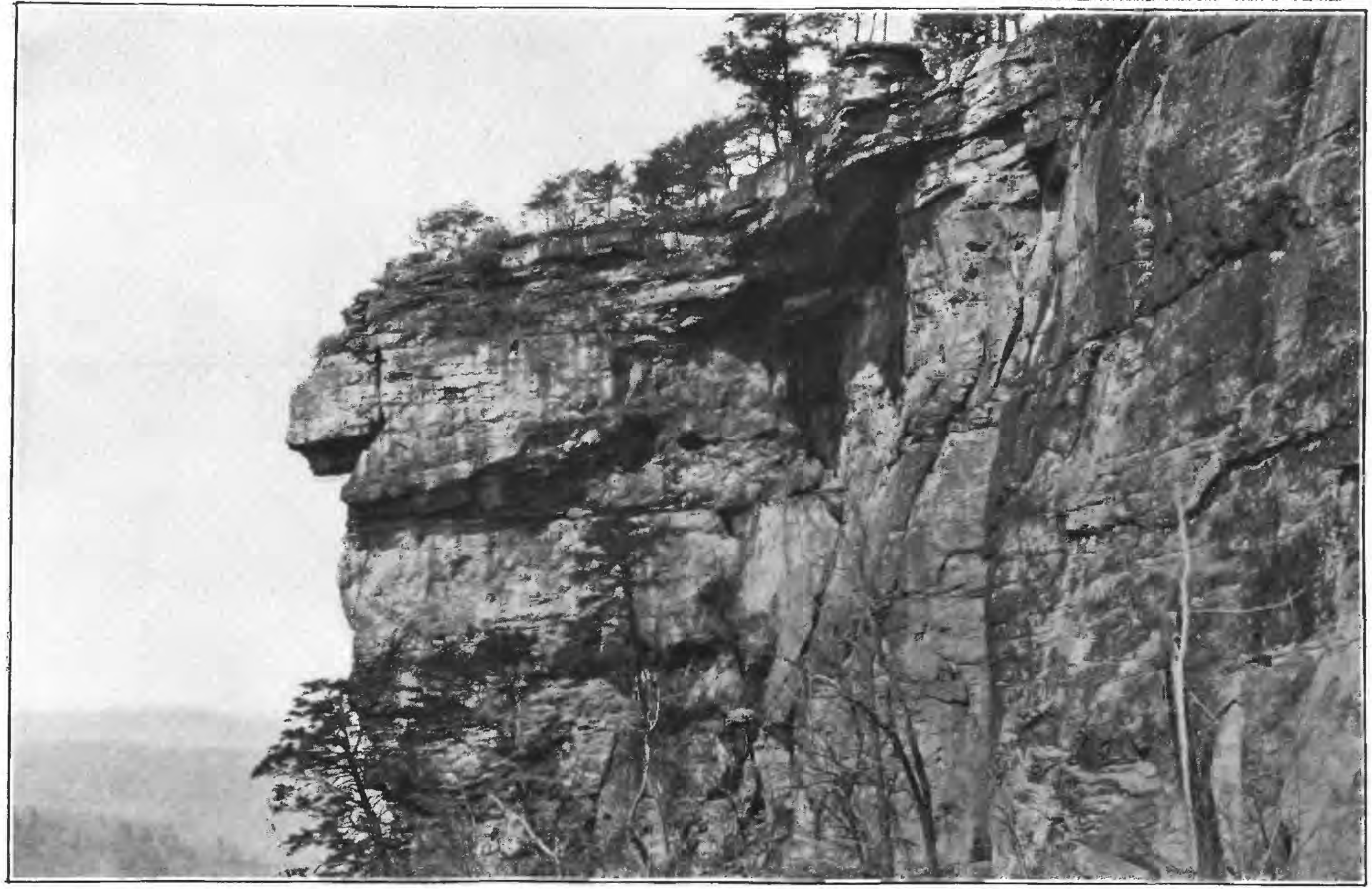
I. C. White, in describing the New River section, has applied the name "Homewood" to the beds which are here denominated the Fayette sandstone, but in the special section at Nuttall he includes only the massive cliff-making member, 110 feet in thickness. There is above the cliff at this point a mass of soft sandstone or sandy shale which makes no showing in outcrop, but which is a portion of the Fayette, as shown at the type locality and at other points down the river.

The finest cliffs of Fayette sandstone occur along the river from Keeney Creek to Fayette station, but the entire formation holds a fairly constant thickness of 180 to 220 feet from Nuttall to Cotton Hill. Below Fayette station the cliffs are still prominent, but the dip has brought them much nearer water level, and hence relieved them of much of their impressiveness. At Gaymont the formation is composed of two plates of coarse sandstone or conglomerate; the lower is somewhat more massive than the upper, with the interval between them composed of soft sandstone and sandy shale.

The lower bed continues massive to Hawks Nest, where it forms picturesque cliffs. About a mile below Hawks Nest the cliffs on the eastern side of the river present a fine section of this sandstone, the top of which is here 500 feet above the river and affords a commanding view up and down the stream. Pl. XLI is a view up the stream from this point, and, although obscured by smoke and haze, it shows faintly the line of cliffs formed by the Fayette sandstone from Sunnyside in the extreme distance to a point directly above the depot at Hawks Nest. The railroad bridge rests upon the Raleigh sandstone; therefore the full thickness of the Sewell formation and the Fayette sandstone is exposed in the cliffs above Hawks Nest.

From Cotton Hill to Gauley Junction the cliffs formed by the Fayette are inconspicuous from the railroad, being dwarfed into insignificance by the much wilder gorge at water level. A measured section below Cotton Hill and one at Blue Hole tunnel show that the formation is still present in about its normal condition and with a thickness of 190 feet.

The rapid dip below Gauley Junction brings the sandstone to water level opposite the mouth of Gauley River, but the sharp westerly swing



FAYETTE SANDSTONE CLIFF.

of the river at this point permits only the lower and more massive bench to disappear below the water. Upon reaching this point the river spreads out into a broad, shallow channel, in striking contrast to the narrow gorge walled by massive cliffs and obstructed by immense bowlders which characterizes its course above this point. This sudden expansion occurs at the junction of New and Gauley rivers, and hence marks the beginning, as conventionally considered, of the Kanawha River.

The heavy bed of the Fayette lifts slightly as the river rounds the bend, and produces the very pretty cascade known as Kanawha Falls. It is generally considered, and has been so stated by I. C. White,[1] that the Fayette sinks so low that its top is about at water level between Kanawha Falls and Gauley, but this is not the case. The massive bed does sink below the river, but the upper portion, which is here thin-bedded, is still to be seen extending 100 feet above the grade of the railroad.

Below Kanawha Falls, in the extreme point of the great southerly bend of the river, the Fayette rises until, on the northern side of the river, 20 feet of argillaceous shale is visible between the track of the Kanawha and Michigan Railroad and the base of the Fayette. The latter is about 200 feet in thickness, and consists of two plates of heavy sandstone with sandy shale between. On the southern side of the river, owing to the steep northerly dip, the base of the Fayette is probably 20 or 25 feet higher than on the opposite side. From this point it gradually descends to the mouth of Loop Creek, where its top is visible 160 feet above the river level. Below Deepwater it goes down rapidly, and passes below water level near the mouth of Armstrong Creek.

There is some uncertainty about the exact point of disappearance of this bed from the river section. Below Deepwater the upper portion appears to break up somewhat into thin beds of sandstone separated by sandy shale. This of itself causes some uncertainty, but the tracing is still further complicated by the increasingly sandy character of the base of the formation next above. This condition of the beds renders the tracing of the upper limit very uncertain, if not altogether impossible below Deepwater.

KANAWHA FORMATION.

Above the Fayette sandstone appears a great mass of coals and sediments, which are 1,150 feet thick at Deepwater, and are economically the most important in the section. Stratigraphically they can not be accurately subdivided without an amount of detailed work altogether out of proportion to the value of the results obtained. The sediments of the formation are shales and sandstones of varying char-

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[1] The Virginias, Vol. VI, p. 16.

acter, and limestones occurring as thin sheets, or as lenses in the beds of shale. In a general way the formation is more argillaceous at the base and more arenaceous at the top, although numerous beds of sandstone occur in the lower portion and also shales in the upper portion.

The shales vary from dark marine beds carrying organic remains to others highly siliceous and scarcely distinguishable from the thin sandstones with which they are associated. The latter are usually coarse, feldspathic, micaceous, and rather soft, and as stratigraphic guides they are not to be relied upon, for their character and thickness are not constant. The sandstones frequently rest unconformably upon the shales, indicating that a period of erosion intervened between the deposition of one and the deposition of the other. No cases have been observed in which the erosion shows great vertical range, yet it is great enough to impress the geologist with the general unreliability of correlations across extended intervals of poor exposures. Good examples of these unconformities can be seen along the railroad between Dego and Handley and between Belmont and Eastbank.

Two carefully measured sections made within a few miles of each other and accurately correlated at the top by the location of the flint and at the base by some well-known coal seam, frequently exhibit surprisingly little correspondence in quantity and position of sandstones and shales. The chief reason for this is the indefiniteness of the lithologic characters of the various beds. Also accidents of exposure will cause the sandy shale to stand out in cliffs, or the softer sandstones to weather as shales, offering, as compared with the Sewell and Royal formations of the Pottsville series, almost no definite lines of separation, and causing one section to appear much more sandy than the other, when in reality it is not so. Under these circumstances more attention must be paid to the coals as aids in stratigraphic work, the developments along the river giving excellent facilities for their use in this connection. Care must be exercised, however, for they partake of the changeableness of the associated rocks.

Limestones are encountered at various horizons, generally as lenticular masses in shales, but also as thin bands. These limestones are sometimes quite pure, but are generally siliceous. It is doubtful if the majority of these beds are continuous over wide areas, but even assuming that they have a wide geographical distribution, they are too thin to be generally exposed, and hence are of but little value for purposes of general correlation.

The "Eagle limestone," 75 feet below the Eagle coal, and the "Cannelton cement" bed, 30 feet above the same horizon, have been fully described by I. C. White.[1] O. A. Veazey carefully measured a section opposite the mouth of Hughes Creek in which no less than seven calcareous beds are exposed, all above the horizon of the "Cannelton cement." The number, character, and distribution of these deposits

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[1] The Virginias, Vol. VI, p. 15.

make their correlation with the well-known beds of eastern Ohio and western Pennsylvania a matter of mere speculation.

Since the Kanawha formation occurs immediately above the Fayette sandstone, the lower beds of the former make their appearance along the course of New River almost simultaneously with the appearance of the latter, but at first only as a thin covering some distance back from the river bluffs. More and more of the Kanawha formation comes in as the sandstone dips below the general level of the upland, until in Gauley Mountain, back of Ansted, the whole formation makes its appearance, the black flint, the upper limit of the formation, appearing near the summit of the mountain. Cotton Hill, on the west side of the river, includes only 800 feet of the base, but the dip of the strata is so great that a complete section is exposed in the hills north of Kanawha Falls. At this point the flint appears for the first time in the hills immediately fronting the river, a position which it holds for a long distance down the river. The Fayette sandstone continues above water level to the mouth of Armstrong Creek, so that north of the river all of the Kanawha formation is exposed in the hills between these two points. On the south side the hills do not rise high enough to catch the flint; hence the section is incomplete on this side of the river. Below Mount Carbon the beds dip gently but irregularly, bringing the top of the formation to water level at Charleston.

For convenience in treatment, the Kanawha coal seams are divided into two groups, an upper and a lower. The lower group includes the Ansted, Eagle, Gas, Cedar Grove, Tunnel, Peerless, Brownstown, Campbells Creek, and associated thin seams. The principal coal seams of the upper group are the Stockton or Crown Hill, the Coalburg, and the Kanawha Mining or Winifrede seams. Between these two groups are about 300 feet of practically barren strata.

LOWER COAL GROUP.

In descending New River the first of these coals to be seen is the Ansted, which is mined on the property of the Gauley Mountain Coal and Coke Company, and which is there about 600 feet below the flint. Presumably the same seam is opened near the summit of Cotton Hill, where it measures 4 feet 8½ inches, consisting of alternate bands of gray splint and bright gas coal. It has been mined on a small scale for use about Fayette, and is reported to be an excellent fuel. Thirty feet below this opening is a small, irregular seam in the sandstone, which is considered by some of the local experts to be a part of the Ansted seam. At Ansted, where it is mined extensively, the total thickness varies from 4 feet 5 inches to 8 feet, with an irregular parting 2 feet below the top; this parting varies in the mine from 4 inches to 4 feet, and is reported to increase toward the northwest until it becomes too thick to remove readily. In this direction the lower bench only, usually about 4 feet 6 inches, is mined.

The Ansted seam is generally considered the equivalent of the Gas seam, but paleontologic and stratigraphic evidence agree in placing it somewhat higher.

The lowest workable coal in this formation is the Eagle, 330 feet above the base of the Kanawha formation. It is opened above the mouth of Loop Creek and is reported by Veazey in Wildcat Branch, opposite Deepwater. At St. Clair, Eagle, and Edgewater it is mined and coked, and has been reached by a slope at Montgomery. This seam is about 810 or 820 feet below the flint, where it first appears in the section at Deepwater, and 730 feet at Montgomery.

The Gas, or Coal Valley, the next higher seam of importance above the Eagle, is now mined at both the upper and lower mines at Mount Carbon, and at Diamond, Forest Hill, St. Clair, Edgewater, Crescent, Montgomery, and Union, and there is an abandoned working at the Consolidated mine above Handley.

The question of the extension and identification of the Gas seam below the Consolidated mine is an interesting one, although of little practical value. By local experts the split in the Gas seam which occurs in the vicinity of Morris Creek is supposed to continue down the river and to produce two distinctly separate seams of coal. The lower bench is generally regarded as the more prominent, and is supposed to show about 80 feet above the mouth of Paint Creek and on the wagon road from Dego to Handley. So far as stratigraphic evidence is concerned, this correlation would seem to be good, but the fossil evidence, of which there is quite an abundance, seems to indicate that the old opening on the road back of Dego and the Gas seam are not one and the same. On this evidence the Gas seam is considered as passing above the Dego coal, and is so indicated on the section.

The interval between the Eagle and Gas seams is 155 feet at Mount Carbon and about 125 feet at Crescent, showing a thinning which conforms to that of the series in general. A coal is reported 110 feet above the Eagle in Wildcat Branch, opposite Deepwater, but its identity is uncertain. If this is the Coal Valley seam, there is a decided lessening of the interval between the two beds eastward from Mount Carbon as well as westward, but the identification is not certain enough to base any speculations upon regarding the variation of intervals.

The Eagle, Gas, and Ansted are the only seams which yield coking coals in the Kanawha Valley.

At Eastbank, on the south side of the river, and at Riverside, Cedar Grove, and Monarch on the north side, coals in the lower group are also mined. In the section at Cedar Grove the interval of 140 feet from the Tunnel seam, reached by a slope, to a coal 1 foot in thickness, 25 feet above the Cedar Grove seam, contains at least five coals, varying in thickness from 1 to 4 feet. This interval includes the horizons of the Gas, Peerless, Brownstown, and Campbells Creek seams, as well as the Cedar Grove and Tunnel seams. Since these coals all come within so limited a vertical interval and that interval contains so many small coals, the question of exact correlation becomes extremely difficult. The tendency among operators is to correlate workable seams of coal and to disregard the obvious possibility that, in a horizon so prolific, a slight thinning of one seam and thickening of another may shift correspondingly the workability of the beds, and that on account of the slight vertical distance between them the change may not be detected without the closest prospecting. The lower coals of the Kanawha series are, like the sediments with which they are associated, so liable to change that nothing can be taken for granted in tracing them, and a change like that outlined above is quite as probable as that a particular coal will continue of workable thickness while the associated ones remain subordinate.

The uncertainty of stratigraphic tracing is well illustrated by an example at the Black Cat mine. Near the bottom of the incline two seams of coal are exposed, of which the upper is much the larger and is generally regarded as the Cedar Grove seam. A study of the fossil plants from these two coals, by David White, shows that the lower and not the upper seam carries the Cedar Grove flora. Hence in the distance from Eastbank to Black Cat the Cedar Grove seam has become insignificant in thickness and a new seam, 44 feet higher in the series, has swelled to almost workable proportions.

The Peerless coal, now mined at Peerless and formerly at Winifrede Junction, is a thin seam, varying in thickness from 2 to 3 feet, but of such excellent quality that, despite its thinness, it can be mined with profit. It probably comes near the base of the Tunnel-Cedar Grove interval, and may be the equivalent of the Tunnel seam. I. C. White, whose work in the Kanawha field was marked by great accuracy and ability, considers this coal a portion of the Campbells Creek coal seam, which he believes to have thickened up at Peerless into eight benches, with a total of 97 feet, including partings. The evidence does not seem to be sufficient to establish the probability of such an hypothesis, and, without very strong evidence, the continuance of a single coal swamp through such a succession of uplifts and subsidences as are necessary to split it into eight coal benches, with partings of sand and shale of varying thicknesses, or even the occurrence of such local variations of level during the period of general quiescence which must necessarily have prevailed during the deposition of the coal beds, seems highly improbable.

That partings do appear in coal seams, and thicken up to considerable dimensions, is a well-established fact which is illustrated by the splits of 15 or 20 feet that are known to occur in the Ansted, Gas, and Campbells Creek seams, but that the occurrence of a number of thin seams within a vertical range of a hundred feet in one locality is best explained by assuming that a heavy bed which occurs near the same stratigraphic position in another locality has swelled by the introduction of numerous partings to the greater thickness, is certainly too broad an assumption. It presumably arises from the attempt to account for all of the coals of the Kanawha formation on the supposition that only the six workable coals of Pennsylvania and Ohio are represented here, a supposition certainly incorrect. Further, it seems inconsistent to admit irregularities in conditions great enough to produce such a change from Campbells Creek to Peerless and yet not admit irregularities great enough to permit the formation of comparatively local swamps and valuable coal beds of limited geographical extent.

The Peerless seam is usually correlated with the seam which was originally worked at Cedar Grove by a tunnel under the Kanawha and Michigan Railroad and now known as the Tunnel seam. Stratigraphically it is impossible to tell whether these seams should be correlated or not. They are evidently very nearly equivalent, but, according to David White, their floras do not show enough resemblance to make them exact equivalents. To the student of Coal Measures geology and others interested in the correlation of individual coal seams the cuts along the Chesapeake and Ohio Railway above Eastbank furnish abundant food for thought and speculation. A short distance above Eastbank, as the railroad enters the side-hill cut, the Tunnel seam is seen to rise very gently above the grade of the road. Above the seam is a varying thickness of dark shale upon which rests unconformably a heavy, coarse sandstone. The surface separating the shale and sandstone is clearly an erosion surface, which is marked by great irregularity, as though the shale had been cut out by strong currents. As a consequence the sandstone in places approaches to within a few feet of the coal; then it lifts to 20 or 30 feet above it, but does not hold to any one position for any distance. A short distance below the Black Cat tipple the Tunnel seam, which is here about 10 feet above the railroad, is suddenly cut off by a great mass of the upper sandstone, and, since the section is covered above this point, it is impossible to tell whether this seam comes in again or not. To the thoughtful student a host of questions are raised by such phenomena, and he begins to doubt the evidence of his senses when attempting to trace coal seams. Thus it is not at all certain that the Tunnel seam is present above Black Cat tipple, but the Peerless flora was found above Dego; therefore if the Tunnel seam does not reappear it can hardly be the equivalent of the Peerless seam. It is still uncertain what correlations will prove correct, but the evidence so far available seems to favor David White's hypothesis that the Peerless is not quite equivalent to the Tunnel seam.

The coal formerly mined at Brownstown and vicinity corresponds very closely with the Peerless in position, but since the former is apparently unfossiliferous and the exposures between Fields and Lenns creeks are poor, neither paleontologic nor stratigraphic evidence is available to make a positive determination of their relationship.

The Campbells Creek coal was long regarded as one of the most valuable seams along the Kanawha River. It occurs in an isolated area about the mouth of Campbells Creek, and is apparently the product of a single limited coal swamp. At its best development the thickness of the seam varies from 4 to 6 feet, but it diminishes from this maximum measure in all directions. The basin is now practically exhausted, but its stratigraphic relation to the seams farther up the river is a very interesting question. In passing up the river from the mouth of Campbells Creek the seam is divided by thin shale partings, which increase in thickness toward the south until the seam covers a vertical range of 15 or 20 feet. This split is indisputable, for much of it has been traced in the mine which supplies the Malden salt works with fuel; but, as before stated, it does not seem probable that the splitting is so extensive as has been stated. Judging alone from its distance below the flint ledge, it would seem to correspond with the Cedar Grove seam; it certainly belongs to this general horizon, but its exact equivalent has not yet been determined.

At Malden, where it dips below grade, the lower group of coals of the Kanawha formation passes out of sight, not to reappear on the eastern side of the basin.

UPPER COAL GROUP.

The important seams comprising this group are three in number and appear to be very constant, in regard both to thickness and to geographical extent. The uppermost of these seams occurs but a short distance below the flint, and is known along the river as the Stockton, Crown Hill, or Lewiston seam. The latter appears to be clearly a misnomer, since the seam which was formerly mined at Lewiston, or Winifrede Junction, is unquestionably the Winifrede seam, here provisionally correlated with the Kanawha Mining seam. The name Stockton is derived from the name of the estate upon which the first operations were begun on this seam at Cannelton, and is here adopted in preference to the name Crown Hill, which is also frequently used along the river. The second seam is universally known as the Coalburg seam from the well-known mine at that place. The lowest seam is generally referred to as the Kanawha Mining from the name of the company first operating on this seam in the vicinity of Montgomery. The impression prevails among local experts that this is the equivalent of the Winifrede, but the correlation is not positive; it is provisionally accepted here as the most probable supposition.

Although the strata which contain this group of coals are present in the river hills as far up as Kanawha Falls, the coals have not been mined above Montgomery, near where the original Stockton mine was located. This was abandoned years ago, and the first mine in operation on any of these seams below Montgomery is the Consolidated. All of the seams have been opened at this point, and all are of workable thickness. The Kanawha Mining seam has been opened at a number of places below the Consolidated mine, but in a great many cases work has been abandoned, and nothing but the incline is left to mark the spot. Mines are in actual operation on this seam at Consolidated, Lower Creek, Crown Hill, and Belmont; and the Winifrede, its supposed equivalent, is mined at Peel, opposite Winifrede Junction, under the name of the Black Diamond seam. The Coalburg seam is mined at Consolidated, Crown Hill, Belmont, Black Cat, Monarch, and North Coalburg. The Stockton seam is mined at Crown Hill, Belmont, and Coalburg.

The intervals between these seams and the top of the flint ledge are shown in the following table:

Intervals between the coal seams.

Locality or name of mine.	Interval between the flint ledge and Stockton seam.	Interval between the flint ledge and Coalburg seam.	Interval between the flint ledge and Kanawha Mining seam.
	Feet.	*Feet.*	*Feet.*
Consolidated	53	88	174
Lower Creek	50	73	193
Dego	58	84	178
Crown Hill	37	132	186
Belmont	38	117	169
Monarch		105	
Peel			200
Winifrede Junction			200

There seems no reason for doubting the identity of these coals at the various points, and a comparison of the intervals shows that the one between the flint and the Stockton seam varies from 37 to 58 feet; that between the flint and the Coalburg, from 73 to 132 feet; and that between the flint and the Kanawha Mining seam, from 169 to 200 feet.

Three seams in the upper group, having a somewhat close resemblance to the three seams showing between Montgomery and Brownstown, have been opened at various points between Malden and Charleston. The Stockton was seen on the head of Rush Creek about 30 feet below the flint, but this interval apparently decreases down the stream. One-half mile below Kanawha City an opening has been made on a seam which immediately underlies the flint, and which is presumably the equivalent of the Stockton seam. Between Kanawha City and Charleston this seam has been opened in many places, but has in every case been abandoned, and hence it is supposed to be of not much value. The flint and the underlying coal are well exposed in a cut of the Chesapeake and Ohio Railway a short distance above Charleston station. There are several small seams below the Stockton, but since none of them are worked it is reasonable to suppose that they are of but little value. One of these, which is from 80 to 100 feet below the flint, corresponds apparently with the Coalburg seam. At a distance varying from 140 to 220 feet below the flint the lowest and most prominent seam of this region is found. Since its interval agrees approximately with that of the Winifrede, it is thought likely to be the representative of that seam. No exposure of the coal was seen, but the old openings are in all cases marked by great heaps of cannel shale, which apparently constitutes the major portion of the seam.

About the mouth of Elk River the top of the Kanawha formation passes below water level, and the river bluffs are composed of the Charleston sandstone.

KANAWHA BLACK FLINT.

The most distinctive horizon in the entire column above the Fayette sandstone is that which long ago Rogers[1] chose as the boundary between his "Upper Coal Series" and "Lower Coal Series." "Its striking peculiarity of character and constancy of geologic position"—the reasons which caused him to make this choice in 1839—are sufficient to justify our choice now. The "Flint Ledge," where present, is recognized by prospectors and mining engineers as a valuable bench mark from which to determine the location of coal seams both above and below its horizon. In its best development it is about 10 feet in thickness, with usually a few feet of accompanying sharp, flinty shale, which represents a transition from the flint to sandy shales above and below. Occasionally, however, it is immediately overlain by coarse sandstone, the change in such a case being very abrupt. Where the flint is heavy it is usually divided by well-marked bedding planes into three or four subordinate strata, 20 or 30 inches in thickness, which within themselves exhibit no traces of bedding, but break into almost indestructible blocks rudely rectangular in shape and of all sizes up to 5 or 6 feet in length. These cover the slopes below the outcrop and form by far the most prominent part of the talus. The flint breaks with a conchoidal fracture and is dark bluish-black on fresh surfaces, but is occasionally bleached superficially to a grayish white.

From the region of maximum development about the head waters of Kelleys Creek it fades toward its margin by reduction in absolute thickness, by increase in bedding planes and fissility, and by becoming coarser in grain and more sandy in texture, until it is impossible to distinguish it from the usual Coal Measures shales. It also appears to be absent from the section entirely at places where its horizon is present, since climbs occasionally fail to reveal any trace of it.

It first appears in the river section in Gauley Mountain back of Ansted, and is not again seen until we reach the hills north of the river in the bend between Kanawha Falls and Deepwater. From the

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[1] Geology of the Virginias, p. 346.

latter point it is almost continuously present down to Charleston. It is best developed and has been most used as a guide by prospectors between Deepwater and Fields Creek. In the hills above Winifrede Junction it is 4 or 5 feet thick, but coarse and sandy. Below this point it is an inconspicuous bed, generally weathering into a hard, thin shale instead of breaking into blocks, as it does east of Cedar Grove. A short distance above Charleston, as stated by I. C. White, it loses its flinty character, and is presumably absent as a flint where its horizon sinks below the river.

CHARLESTON SANDSTONE.

The coals and sediments, the latter usually coarse, which overlie the flint and extend up to the red shales, are all exposed in the bluffs back of Charleston and have been designated the Charleston sandstone. Being immediately above the flint, they are practically coextensive with it to the southeastward, but downstream they extend for a short distance below Blackband, the limit of the section. In thickness the formation shows the usual phenomenon of a southeastward expansion. Back of Handley, toward the head waters of Upper Creek, 420 feet of sediment are found above the flint, and the top has been removed by erosion. In the section above Dego 380 feet of sandstone and conglomerate are given by Veazey. At several points between Dego and Charleston from 100 to 300 feet of these beds have been measured, but without reaching the red shale. The only complete section that we have is at Charleston, where a total of 320 feet was measured.

The beds are frequently conglomeratic, but the pebble-bearing horizons vary greatly in different portions of the field. The sandstones are usually feldspathic and friable, although a bed occasionally develops character enough to locally stand out as a cliff, and the pebbles of the conglomerate, although predominantly quartz, are sometimes of chert and jasper.

The coals are practically confined to two horizons, the No. 5 or Cannelton block and the North Coalburg. The Cannelton block is found from 50 to 80 feet above the flint, and in the region about Crescent, Edgewater, and Morris Creek, averages from 5 to 6 feet in thickness. At Cannelton it is one of the beds which has yielded the cannel coal that gives the town its name. It has been opened at several points along the river below Crescent, but is not mined commercially. At the Monarch mine it is 85 feet above the flint, and at North Coalburg Lewis gives the interval as 66 feet, but the bed is thin in each instance. Near Charleston it has been opened and used locally by several land owners, but does not prove to be worth extensive development.

The North Coalburg seam is mined only at North Coalburg and Monarch, although known at other points. It is in the sandier portion of the Charleston formation, and seems to be very irregular. Besides these principal seams, a small one is sometimes found immediately over the flint. A coal at this horizon has been called the Middle Cannelton by I. C. White, but it is slaty and worthless, as he states, whereever known.

The following analyses illustrate the composition of the various coals of the Kanawha and Charleston formations:

Analyses of coals of the Kanawha and Charleston formations.

Locality.	Name of seam.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.
North Coalburg	North Coalburg	0.99	36.63	54.49	7.89	0.94
Cannelton	No. 5 (cannel)	0.49	43.06	39.44	17.01	0.31
Crown Hill	Stockton	2.14	33.26	62.61	1.81	0.18
Coalburg	Coalburg	3.65	33.50	62.00	1.50	0.35
Winifrede	Winifrede	1.06	34.93	54.90	9.11	0.50
Cedar Grove	Cedar Grove	....	36.83	60.67	2.50	....
Ansted	Ansted	0.84	34.18	57.75	7.23	0.87
Campbells Creek	Campbells Creek	1.51	35.64	61.07	1.21	0.37
Crescent	Gas	0.78	38.57	56.40	4.25	1.44
Peerless	Peerless	0.95	39.64	57.18	2.23	0.67
Eagle	Eagle	2.35	22.90	70.47	2.50	1.78

NORTHWARD THINNING OF THE FORMATIONS.

The great discrepancy between the thickness of the various formations on the eastern and western sides of the Appalachian Coal Field has always been an interesting subject for speculation. As a rule, the lack of data in the center of the basin has rendered most statements concerning it entirely speculative, but of late years the drill has added something to our knowledge of the thickness and composition of the lower members near the middle of the basin where they are under cover.

The section along the New and Kanawha rivers shows something of this westward thinning, although it embraces but a part of the eastern limb of the basin. Taken in connection with some well records near Charleston, however, it shows a wonderful decrease in thickness, and since but little of this thinning can be seen above the bed of the river we are forced to the conclusion that the major portion of the change occurs near the base of the formations.

The question is still further complicated by the uncertainty which attaches to the upper limit of the red shales, even in that portion of the section in which they are above the level of the stream. If we can not determine their upper limit when exposed in the river gorge, what can we expect when the evidence rests entirely upon drill records?

The maximum measure of the various formations exposed along the river generally occurs at the most southerly point at which the full thickness is present in the river gorge. Thus the greatest measure of the Royal formation, excepting the red shales, 150 feet in thickness, which occur at its base, is 880 feet; the Raleigh sandstone, 100 feet; the Sewell formation, 500 feet; the Fayette, 220 feet; and the Kanawha formation, 1,200 feet. Arranged in tabular form, the formations included within the limits of the red shale below and the flint above show the following maximum thicknesses:

Thicknesses of formations between the red shale and the flint.

	Feet.
Kanawha formation	1,200
Fayette sandstone	220
Sewell formation	500
Raleigh sandstone	100
Royal formation	880
Total	2,900

The record of a well drilled at Charleston, according to I. C. White,[1] shows the base of the coal-bearing formations to be 1,150 feet below the level of the city; and since the black flint is practically at grade at this point, the well measure is the combined thicknesses of the various formations as tabulated above. Since sediments to a thickness of 2,900 feet accumulated upon the southern margin of the basin and only to the extent of 1,150 feet in the vicinity of Charleston, it means a thinning in the section (101.4 miles) of at least the difference between them, or 1,750 feet.

Upon examination of the section it is seen that the Royal formation shows a trace of this thinning, although its lower limit is uncertain. Its maximum measure, less the probable thickness of red shale, is 880 feet, and its minimum, after making the same allowance, is 790 feet. This shows a diminution of 90 feet. The Raleigh sandstone shows a decrease of 40 feet before it disappears below the level of the stream. The Sewell formation suffers more than the others, showing in the interval from Caperton to Hawks Nest 220 feet. The Fayette sandstone shows but 20 feet of northwestward thinning along the river section. The Kanawha formation is much more difficult to measure on account of the lack of well-marked horizons. The interval at Mount Carbon between the Gas seam and the flint is 660 feet, and at the Consolidated mine the same interval is but 540 feet; hence the thinning in this interval between these points is 120 feet. From Brownstown to Charleston a thinning of 130 feet can be detected by tracing the coal seams from point to point and comparing them with the flint horizon above. These various items, when collected, show a total decrease in thickness, observable in the section, of 620 feet.

Thus, in a total decrease of 1,750 feet, 620 feet can be accounted for,

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[1] Bull. U. S. Geol. Survey No. 65, pp. 136, 195.

leaving 1,130 feet which is either unnoticed above the stream or else takes place below that level.

A small portion of this amount can be accounted for by comparing the records of the Charleston and Brownstown wells. Generally the records of these wells are so vague and indefinite that minor subdivisions can not be recognized, but the change from the coarse sandstones of the Pottsville series to the calcareous shales and limestones of the Hinton formation is sharp and generally recorded. By such records we know that the base of the coarse sandstones at the mouth of Witchers Creek is 890 feet below grade; if this is added to the elevation of the flint above grade at the same point, it gives 1,480 feet as the total thickness of the formations which at Charleston measure only 1,150 feet. Hence a total thinning of 330 feet is established. But in this distance a decrease of 130 feet was observed above the river; consequently a change of 200 feet must have taken place below water level.

Thus from a total of 1,730 feet we can deduct 800 feet as recognized thinning, and have left a remainder of 930 feet, which probably occurs under cover between Beechwood and Brownstown.

This is but a presentation of the facts and figures available at present concerning the changes in the formations between the eastern margin and the center of the Appalachian Basin. The writers are fully aware that it does not throw much light on the interesting question of how the change occurs. More accurate records of wells in various portions of the section are necessary before the question can be even approximately answered.

THE TENNESSEE PHOSPHATES.

BY

CHARLES WILLARD HAYES.

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THE TENNESSEE PHOSPHATES.

By CHARLES WILLARD HAYES.

INTRODUCTION.

The fact that considerable quantities of high-grade phosphate occur in western-middle Tennessee was discovered in the latter part of 1893. The Report on Mineral Resources for that year contained a brief account of the deposits by Mr. C. G. Memiuger. During the following year several accounts of the deposits, both in their geologic and in their economic relations, were published, chiefly by Dr. Safford, State geologist, and various chemists and engineers engaged in the commercial development of the deposits. Two short visits were made to the region by the present writer, and a report embodying all the information obtainable, both from personal observation and from the writing of others, was published last year.[1] During the summer of 1895 a topographic party, under the charge of Mr. A. E. Murlin, topographer, was engaged in mapping the phosphate region. On the completion of the topographic map, the writer, assisted by Mr. H. B. Goodrich, assistant geologist, spent five weeks in November and December in making a detailed examination of the phosphate and associated formations. The present report is the result of that field work.

The general geologic relations of the phosphate region have been fully stated in previous publications, and hence that phase of the subject will be treated very briefly in the present report. Most of the information is conveyed by graphic means upon the maps and sections.

CLASSIFICATION OF THE PHOSPHATES.

The Tennessee phosphates fall into two groups, each of which is further subdivided into a number of varieties. The following scheme of classification expresses the relations of the several varieties, viz:

I. Black phosphate (original deposition).
    1. Nodular.
    2. Bedded.
        Oolitic.
        Compact.
        Conglomeratic.
        Shaly.

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[1] Sixteenth Ann. Rept. U. S. Geol. Survey, Part IV, 1896, pp. 610-630.

II. White phosphate (secondary deposition and replacement).
  1. Stony.
  2. Breccia.
  3. Lamellar.

This classification differs somewhat from that previously employed, particularly with reference to the white phosphates. The reasons for the changes will be given when the latter are considered.

The first group is of Devonian age, and, as indicated above, its members are original constituents of the stratigraphic series; in other words, they were deposited in their present position immediately before or after the deposition of adjacent formations, and have been changed from their original form only by the process of consolidation which affects all deeply buried sediments. They have been changed from mud and sand into compact rock, exactly as have the nonphosphatic beds above and below.

The second group, on the other hand, appears to be wholly secondary. Its members, the white phosphates, probably do not occupy the position and form they had when first deposited. The material has been moved from its original position and redeposited in a different form. The present deposits are extremely young, probably having been formed in the last geological period preceding the present.

GENERAL RELATIONS OF THE PHOSPHATE DEPOSITS.

Before describing the several varieties of phosphate, it will be necessary to give a brief account of the geography and the geology of the region in which they occur. Although one variety, the nodular phosphate, has a wide distribution over parts of several States, including Tennessee, Georgia, Alabama, and probably Arkansas, it has no economic value, except where associated with the more important bedded rock in western-middle Tennessee.

PHYSIOGRAPHY OF THE REGION.

The accompanying index map, Pl. L, shows the location of the four large-scale maps on which the distribution of the phosphate deposits is represented. They are seen to occupy portions of Hickman, Lewis, Perry, and Wayne counties, which lie southwest of Nashville and east of the Tennessee River. This region is a part of the Highland Rim, which borders the central basin of Tennessee. In recent geologic times it was a smooth plain near sea level, but later was lifted to its present altitude, and the streams, accelerated by the uplift, have since cut deep channels in its once smooth surface. The remnants of this old plain have an altitude of a little less than 1,000 feet above sea level, while the channels of the large streams are 500 or 600 feet lower. In the vicinity of the larger streams, particularly the Tennessee River, the surface is deeply dissected by stream channels which have considerable breadth, and adjacent valleys are separated only by narrow ridges. At some distance from the large streams the surface is much less dissected and the stream channels are shallow, narrow, and separated by broad areas of the old plain.

The preservation of so large areas of this old plain is due to the character of the underlying rocks, which are earthy limestones containing many beds of chert. The latter offer considerable resistance to erosion. A little farther east, in middle Tennessee, where purer limestones formed the surface of the plain, erosion was much more rapid and the whole surface was reduced to the lower level. Thus the upper portion of the Duck River Valley is broad and level, forming a portion of the central basin, while its lower course is in a comparatively narrow gorge through the harder rocks of the Highland Rim.

STRATIGRAPHY OF THE REGION.

The formations reaching the surface in this region include a part of the Silurian, the whole of the Devonian, and a part of the Carboniferous. Their relations to one another are shown in the several vertical sections, Pls. LI and LII.

The Silurian limestone, as indicated on the accompanying maps, comes to the surface in most of the stream valleys and extends varying distances up the adjacent slopes. It is generally a hard blue limestone in beds from a few inches to several feet thick, often highly fossiliferous. The Devonian, although never more than 10 or 12 feet thick in this region, is composed of a number of beds, each having definite characteristics which persist over considerable areas.

They are arranged as follows:

Carboniferous		Cherty, shaly limestone
Devonian	D	Greensand with phosphatic nodules, 8-14 inches
	C	Carbonaceous black shale, 0-6 feet
	B	Bedded phosphate, 0-40 inches
	A	Gray sandstone, 0-6 feet
Silurian		Blue limestone

(A) At the base of the Devonian, resting on the Silurian limestone, is a bed of gray sandstone, very compact, and in some places approaching a quartzite. It is thickest near the Tennessee River, where it is in places from 4 to 6 feet thick. It thins eastward, and is wanting on Swan Creek, unless represented by a few inches of shale, which is found at some points at the top of the limestone.

(B) Above the gray sandstone, where that member is present, and elsewhere resting directly on the blue Silurian limestone, is the most important member of the Devonian series, the black bedded phosphate. Its distribution and variation in thickness and character will be more fully described on a subsequent page.

(C) Above the phosphate bed is generally, though not always, a bed of black, highly carbonaceous shale, from an inch up to 4 or 5 feet in thickness. This is the thin edge of the Chattanooga black shale which in East Tennessee is 15 feet or more in thickness and in Kentucky and

Virginia increases to several hundred feet. It somewhat resembles cannel coal, for which it is frequently mistaken. In a few places it is comparatively free from carbonaceous matter, being a bluish-gray, muddy shale. Generally, however, its appearance is extremely uniform and characteristic. It often contains considerable iron pyrite, so that its weathered outcrops are stained with iron oxide and sulphate, while the shale gives rise to many mineral springs.

(D) Finally, above the black shale is a thin stratum, from 8 to 14 inches thick, increasing to 3 feet in East Tennessee, which is the most persistent member of the Devonian series in the region. It consists of a greenish or bluish-gray earthy sandstone, sometimes with an irregular shaly structure, and generally containing abundant phosphatic concretions. The bed is always deeply weathered, and it is therefore difficult to determine its true character. At some distance from the surface it has a deep-green color and contains abundant small pyrite crystals.

In the Batesville region of Arkansas a thin stratum of rock having almost identically the same appearance as that described above is mentioned by Penrose[1] as occupying a corresponding stratigraphic position immediately below the Carboniferous. He describes it as containing "small siliceous concretions, an eighth of an inch to 1 inch in diameter." These concretions have since been examined chemically and found to be highly phosphatic, which strongly confirms the view that the stratum in Arkansas is identical with the one in Tennessee. A thin section of the Arkansas rock was examined by Dr. Wolff, of Harvard University, who "found evidence pointing to the possibility of its being composed partly of volcanic ash." As stated in a previous report,[2] thin sections of this rock from Tennessee were examined, and while they did not afford conclusive evidence, they suggested the possibility that it might be a volcanic ash. During the past season opportunity was offered for obtaining specimens of the unweathered rock, and on examining sections of these its true character was at once apparent. Instead of being a volcanic ash the rock is composed largely of glauconite, or greensand, a silicate of iron and potash. In addition to the glauconite, which closely resembles that from the Cretaceous greensands, there are numerous small pyrite crystals, fine dust-like carbonaceous grains, angular and rounded quartz grains, and a few ovules of lime phosphate. The latter are transparent, with a brown or amber color, and are completely isotropic in polarized light. They show no cleavage or crystal structure, but occasionally traces of organic structure. Wolff describes exactly similar grains in the Arkansas rock, which he says "look like possible fragments of a ferruginous basaltic glass." That these isotropic grains are phosphate is evident when they are compared with sections of the bedded phosphate rock, the latter being composed almost entirely of such ovules.

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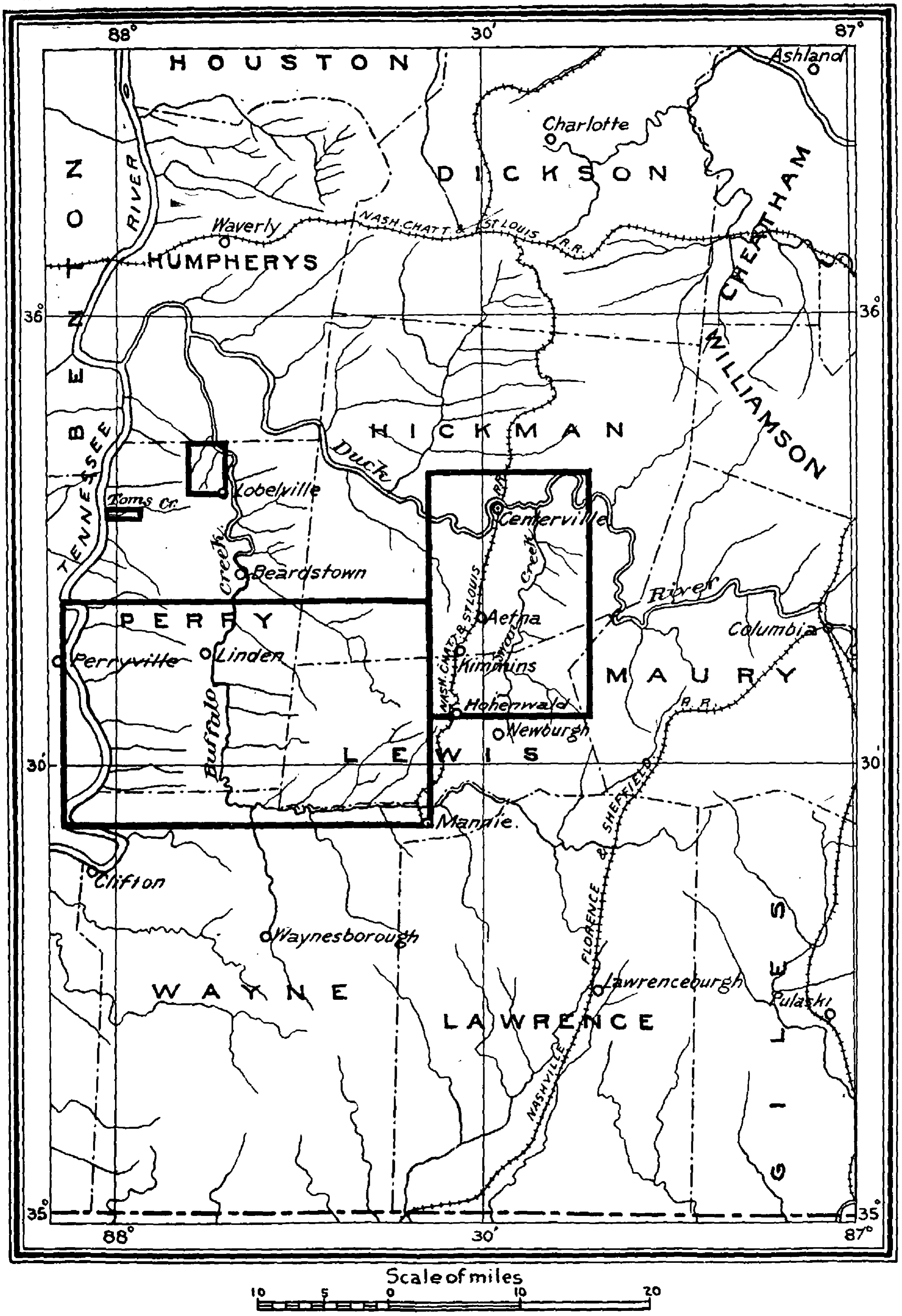
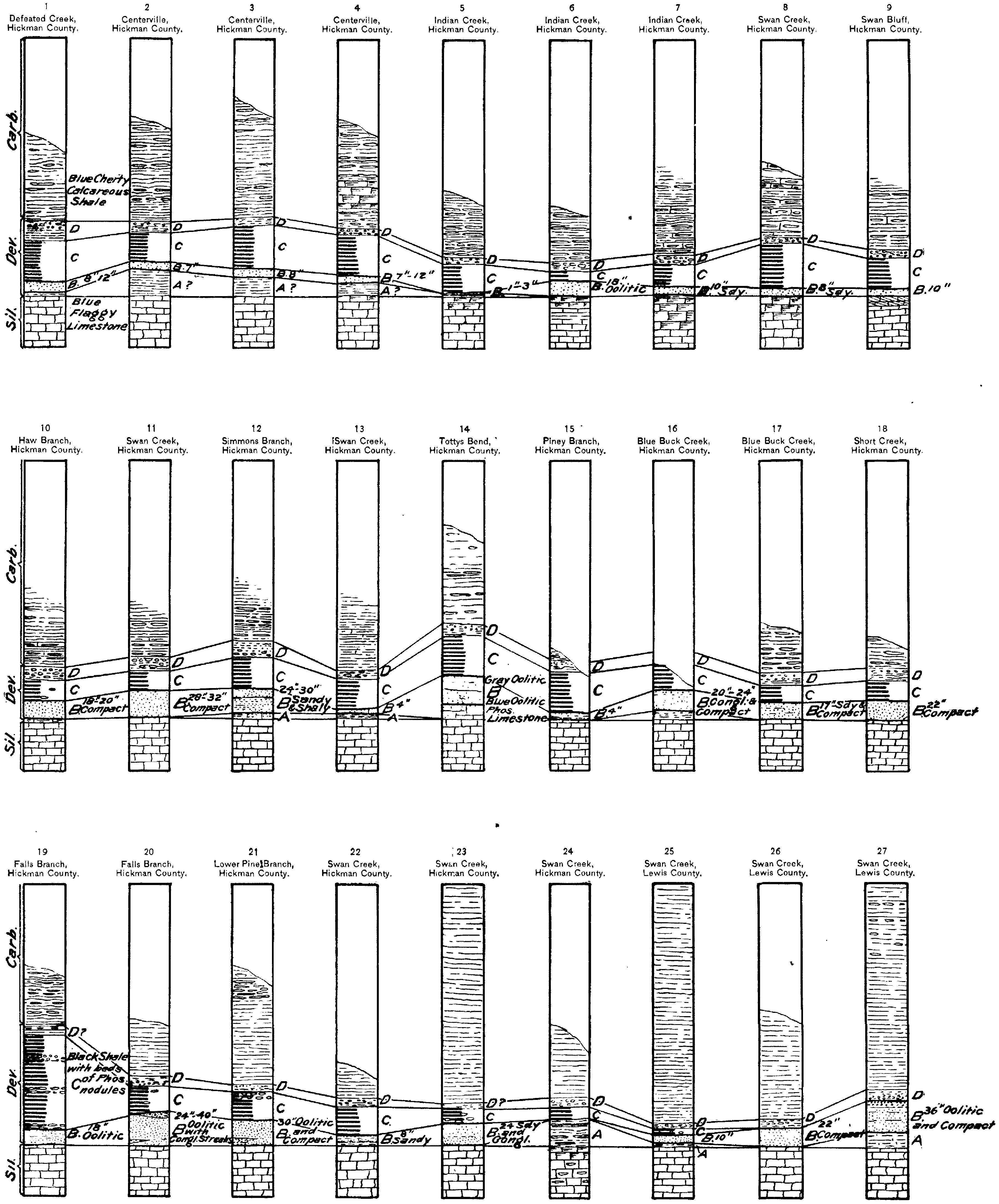
[1] Arkansas Geol. Surv., Ann. Rept. 1890, Vol I, p. 126.

[2] Sixteenth Ann. Rept. U. S. Geol. Survey, Part IV, 1896, p. 612.

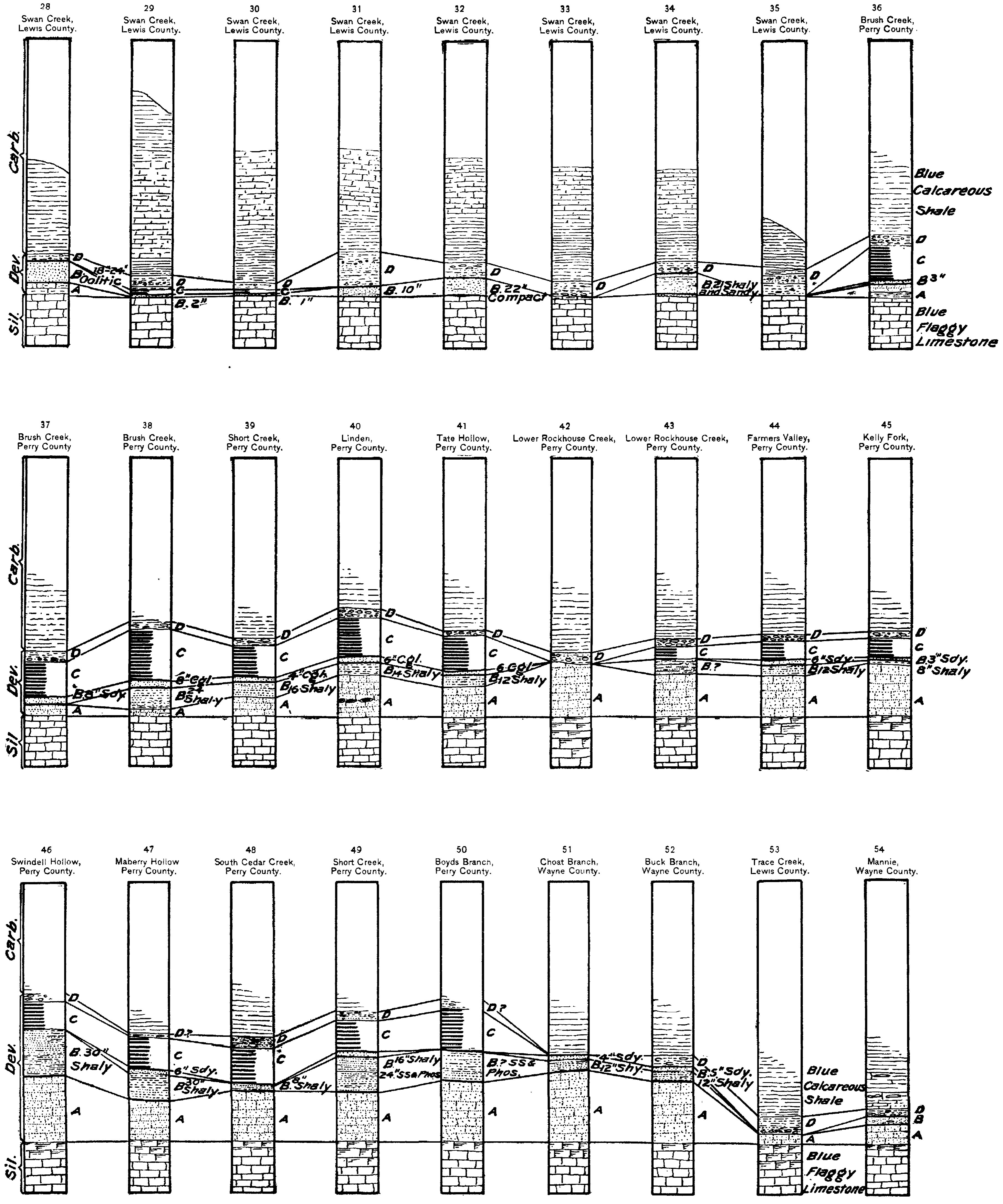


MAP SHOWING LOCATION OF PHOSPHATE DISTRICTS.



SECTIONS SHOWING VARIATIONS IN THICKNESS OF THE PHOSPHATE BED AND ITS RELATIONS TO ADJACENT FORMATIONS.

Scale: 1 inch = 10 feet.



SECTIONS SHOWING VARIATIONS IN THICKNESS OF THE PHOSPHATE BED AND ITS RELATIONS TO ADJACENT FORMATIONS.

Scale: 1 inch = 10 feet.

The last-described greensand bed is immediately overlain by rocks of Carboniferous age, the Harpeth shale of Safford. In some cases it is impossible to determine within a few inches the line separating the two formations, the greensand passing into a bluish clay-shale, fissile at the base, but massive and more calcareous a few feet above. This blue calcareous shale is in some places, as in Lewis County, 40 feet thick, passing into a cherty, earthy limestone at that distance above the top of the Devonian. Generally the chert beds are much nearer the base of the Harpeth, and often rest directly upon the greensand without the intervention of any shale. The position and amount of the chert in this formation are variable, and no subdivision can be made which will hold for any great distance. The formation extends to the summit of the dissected plateau, being at least 300 or 400 feet in thickness. It is rarely exposed, the surface being deeply covered with a mantle of residual chert and clay derived from it in the process of weathering. Further reference will be made to these Carboniferous rocks in connection with the white phosphates.

The formations above described are all of sedimentary origin—that is, they were laid down in approximately horizontal layers upon the sea bottom. Although they have been perhaps several times elevated and depressed since their deposition, they have retained almost exactly their original horizontal position. The beds show a few slight flexures, usually too gentle to be easily detected, but rarely, as in the southern part of Perry County, having a perceptible dip. The axes of these flexures are somewhat irregular, but appear to have a general northeast-southwest trend, approximately parallel with the axes of the central basin and the folds of East Tennessee.

Having briefly described the general relations of associated formations, the several varieties of the black phosphate will now be taken up somewhat in detail.

I. BLACK PHOSPHATES.

BLACK NODULAR PHOSPHATE.

The appearance, distribution, and geological associations of this variety were treated somewhat fully in the previous report, above cited, and but little additional is to be said concerning it. The discovery that the green sandy shale with which the nodules are most often associated is composed largely of glauconite, instead of volcanic ash, suggests analogies with phosphatic concretions in other regions and at other geological horizons; such, for example, as the phosphatic concretions and associated glauconite in the Cambrian sandstones of New Brunswick[1] and those found in the Cretaceous greensands of England.[2]

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[1] On phosphate nodules from the Cambrian of southern New Brunswick, by W. D. Matthew: Trans., New York Acad. Sci., Vol. XII, 1893, pp. 108-120.

[2] On the phosphatic nodules of the Cretaceous rock of Cambridgeshire, by Osmond Fisher: Quart. Jour. Geol. Soc., London, Vol. XXIX, 1873, p. 52.

The nodules vary in size and shape, from nearly spherical bodies one-half to 1½ inches in diameter to irregular flattened ellipsoids sometimes 2 feet in length and a third or a quarter as thick. They have smooth surfaces, separating readily from the inclosing matrix, and show no external evidence of organic origin. They usually weather more easily than the matrix, and then form a gray powder in the center inclosed in a harder and darker shell. They sometimes weather almost white, and often show a concentric banding of different shades of gray. Thin sections of the nodules examined under the microscope show them to be composed chiefly of an amber-colored amorphous substance with grains of pyrite and carbonaceous matter, and in some cases showing a concretionary structure consisting of very minute radial, globular, and mammillary forms. The spaces between these radial forms are generally filled with secondary silica, though sometimes they are empty. Occasional traces of organic forms are seen in the thin sections, but these have not yet been sufficiently studied for identification.

In some of the nodules, though not generally, there is an arrangement of the material in separable concentric shells. More often there is only a slight difference in density and in coloring matter at different distances from the center. Throughout most of the region in which they are found the nodules are small and confined to the bed of greensand at the top of the Devonian, generally forming a more or less closely packed layer near the top of the black shale. In the Swan Creek district, although most abundant at this horizon, they are by no means confined to it, but occur also in the black shale, and even in the phosphate bed. One of the sections, No. 19, Pl. LI, on Falls Branch, shows three layers of these nodules in the black shale, which here has an unusual thickness of nearly 10 feet. The nodules of the lowermost layer, which are also the largest, rest directly upon and are partly embedded within the phosphate bed. The numbers of the nodules vary widely within short distances. Thus, in a prospect pit at one point on Blue Buck Creek they are so abundant in the 3 feet of black shale that they give the section the appearance of a rubble wall, while another section a few hundred feet distant displays the same thickness of black shale without a single nodule. The nodules contain from 60 to 70 per cent of lime phosphate, a little more in weathered than in unweathered specimens. They are not known to occur at any point in sufficient quantity to pay for separate mining apart from the bedded rock. When, however, the latter is mined by stripping off the overburden, the nodules are saved without additional cost, being easily separated from the inclosing shale, and they will thus make it possible to work with profit a thinner bed than could be worked if they were not present. The nodules are not included in the thickness of the phosphate represented on the contoured maps, since their distribution is much too irregular for any such graphic representation.

BLACK BEDDED PHOSPHATE.

This embraces a number of varieties more or less distinct in appearance and composition. The differences are evidently due to the slightly different conditions which prevailed in various parts of the region while the phosphate was being deposited. Before discussing the subject of distribution the several varieties will be briefly described.

Oolitic phosphate.—This variety on the weathered outcrop has the appearance of a rusty, porous sandstone. On close examination of the unweathered rock the constituent grains are seen to be small round or flattened ovules, giving it an oolitic structure. The ovules are bluish-black or gray, with a glazed surface. Associated with them are many fragmentary casts of very small coiled shells, generally well rounded and with the same glazed surfaces as the ovules, so that they add to the appearance of oolitic structure. These ovules and casts are embedded in a fine-grained or structureless matrix. This is more easily soluble than the ovules and disappears as the rock weathers, leaving a porous, loosely compacted mass of the less soluble grains. The rock varies in color from light-gray to bluish-black, the latter being much the most common form. It contains considerable pyrite in fine disseminated grains, and spherical aggregates of crystals sometimes 2 inches in diameter.

Thin sections under the microscope show the color to depend on the amount of finely disseminated carbonaceous matter which the rock contains. In the gray rock from Tottys Bend this carbonaceous matter is almost entirely wanting, while in the black rock from the same locality and elsewhere it is very abundant, in some cases rendering the section nearly opaque. The lime phosphate itself has the appearance of a light-amber or yellowish-brown flocculent material, which is entirely amorphous, showing no double refraction. This material forms the well-defined ovules and fossil casts, and also the groundmass in which they are embedded. The latter is in part structureless and in part composed of small, poorly defined ovules. A majority of the larger ovules are evidently casts of the interior of coiled shells, but are generally worn to an oval form, so that their original form is often nearly obliterated. In addition to the casts of shells, there are numerous fragments of corals, and perhaps other organisms, all well rounded. In some cases they are made up wholly of lime phosphate, the internal structure of the organism being preserved and brought out in the section by varying amounts of carbonaceous matter in different portions. In others the septa or partitions are composed of calcite, as they were originally, while the canals in which the animals lived are filled with phosphate. Adjacent ovules often show a wide difference in the amount of carbonaceous matter which they contain, one being quite opaque and another almost colorless. This, taken in connection with other facts, would seem to indicate that the ovules were formed while lying free upon the sea bottom, and that there was considerable transportation, those formed at one point being drifted to another where the conditions were somewhat different. In the phosphatic limestone which at some points underlies the phosphate bed, the same ovules and rounded fossil casts are seen scattered through a groundmass of calcite.

Compact phosphate.—This variety resembles a homogeneous fine-grained sandstone. It has a dark-gray or bluish-black color, and weathers less freely than the oolitic variety to a compact yellowish sandstone. The weathering proceeds inward from an exposed surface very evenly, and the outer weathered shell is separated from the fresh rock within by a thin layer of light-gray rock—that is, the carbonaceous matter is removed first, and with it the dark color, while the oxidation of the iron, giving the rusty appearance, follows later.

The constituent grains of the rock are distinguished with difficulty even with a good hand glass, and the shell casts are generally absent. When examined under the microscope the rock is seen to be made up of small ovules and fossil casts closely packed together, without the amorphous or granular groundmass observed in the oolitic rock. The ovules are nearly all flattened, and are arranged with their long axes parallel. Many corals and other organisms occur replaced by lime phosphate, as in the rock above described, but the coiled-shell casts which are there so abundant seem to be entirely wanting.

Conglomeratic phosphate.—The two varieties of bedded phosphate above described, together with the nodular variety, embrace all the high-grade black phosphate thus far discovered in Tennessee—that is all containing 70 per cent or more of lime phosphate. Closely associated with the oolitic and compact varieties, and often entirely replacing them, are beds of coarse sandstone or conglomerate containing varying amounts of phosphate. They are usually black or gray, and, like the other varieties, weather to rusty sandstone. In some cases the constituent grains are embedded in a matrix of much finer material, and in others they are closely compacted without a groundmass. They vary in size from extremely fine grains to coarse sand grains one-fourth of an inch in diameter. These grains are partly phosphate ovules similar to those making up the oolitic rock, and partly quartz. In addition to these smaller grains which make up the greater part of the rock are many pebbles apparently well waterworn, some of which are an inch or more in diameter. They are composed of hard, black phosphate, so fine grained and homogeneous as to resemble black flint. Sections of the conglomerate under the microscope show a great variety of structures. The proportion of quartz to phosphate varies widely, although the latter generally predominates. The quartz grains are well rounded, and suggest the forms of wind-blown sand. The phosphatic ovules resemble those forming the oolitic rock, but a much smaller proportion show organic forms, generally corals and rarely shell casts. Sections of the large pebbles show a mottled, yellowish-brown groundmass of phosphate, with much carbonaceous matter and numerous minute organic forms, some of which suggest sponge spicules; also occasional well-defined ovules of light-amber phosphate embedded in the darker groundmass.

Shaly phosphate.—This variety has the appearance of a dark-gray or black fine-grained shaly sandstone. The shaly structure is sometimes pronounced, the rock splitting into extremely thin sheets; in other cases the layers are an inch or several inches in thickness. They usually have a black, glazed surface, more carbonaceous than the remainder of the rock. Some parts of the bed often resemble very closely the compact phosphate above described, but in thin sections it is seen to be composed largely of fine grains of angular quartz embedded in a carbonaceous and phosphatic matrix. This variety is somewhat deceptive, and generally contains less phosphate than its appearance would indicate. It frequently passes into a gray quartzitic sandstone similar to that which almost invariably underlies it. It rarely contains phosphatic ovules or casts, although lingulas are very abundant on the partings between the shaly layers.

DISTRIBUTION OF THE BLACK PHOSPHATE.

The commercially important deposits of black phosphate, so far as known, are, with a few unimportant exceptions, confined to the region represented on the two accompanying maps, Pls. LIII and LIV. These maps are intended to show the distribution of the bed, and, within certain limits, its thickness at any particular point. The maps were constructed by locating a large number of points at which measures of the bed were obtained, and then drawing lines through points of equal thickness. Contour lines were thus obtained showing the variation in thickness throughout the field. Where the bed has been removed by erosion, and where it is deeply covered by overlying formations, the contour lines are, to a certain extent, hypothetical. The interval between adjacent contours is 6 inches, and five contours are given, indicating variations in thickness from 0 to 24 inches and over.

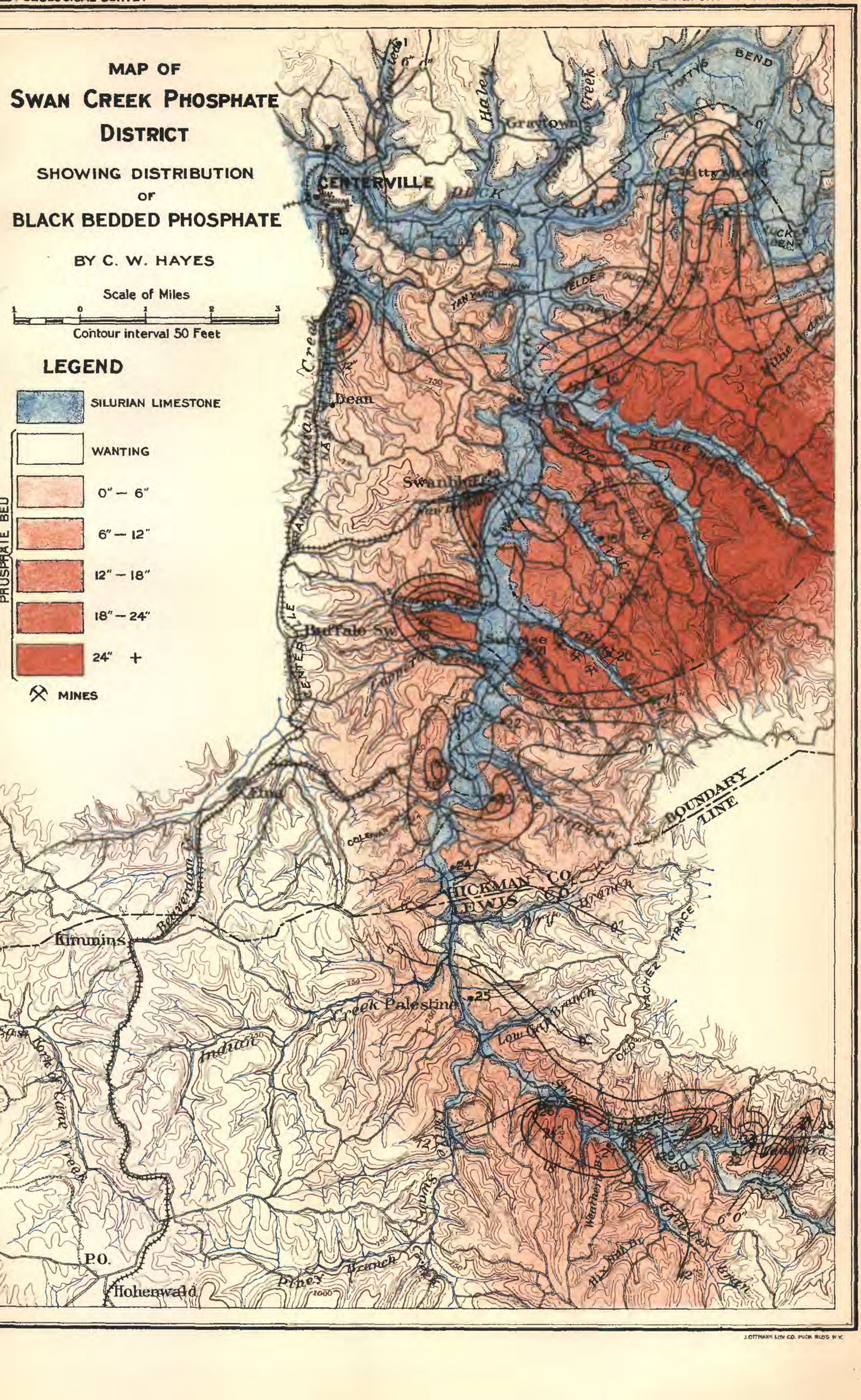
In the practical development of the region two factors chiefly determine whether the phosphate can be worked with profit at any particular point. These are the thickness of the bed and the grade of the rock. If it is exceptionally high-grade rock, a bed 12 inches thick can be worked under favorable conditions, while if the rock is below a certain grade it can not be worked, no matter how thick the bed may be. Hence it must be clearly understood that the map is intended to give information concerning only one of these factors. Some territory lying near the 18-inch contour is much more valuable than other areas lying within the 24-inch contour. Some information on the second point, the grade of the rock, is contained in the following description of the various parts of the field, and also in the numerous sections forming Pls. LI and LII. Thoroughly satisfactory conclusions as to the grade of the rock can be obtained, however, only by many chemical analyses, and hence are beyond the scope of this report.

An examination of the maps shows that the variation in thickness of the phosphate bed is quite irregular. The thickest portions are small, partially or completely isolated areas which apparently have no determinable system in their arrangement. These areas will now be taken up and described somewhat in detail.

THE SWAN CREEK DISTRICT.

The first of these isolated areas lies in the vicinity of Centerville Hickman County, Tenn. Its location is shown on the map, Pl. LIII, and the variations in the thickness of the phosphate bed are shown in sections 1 to 7. It will be seen from an examination of the sections that all four members of the Devonian formation are here present. The lowermost, which, as stated above, is generally a bed of hard gray sandstone, is here represented by a few inches of clay-shale resting immediately upon the blue flaggy Silurian limestone. Above this is the phosphate bed, and then, in turn, the black shale and greensand, the latter containing numerous small phosphatic nodules. In the sections 1 to 4, taken on a line north and south through Centerville, the phosphate bed has a thickness of from 7 to 12 inches. It is slightly oolitic and a rather high-grade rock, but evidently too thin for profitable working. In section 5, on Indian Creek, about 2 miles south of Centerville, the phosphate bed nearly disappears, decreasing to 1 or 2 inches. From this point southward it increases rapidly, and, as shown in section 6, also on Indian Creek, it has a thickness of 18 inches of high-grade rock, largely oolitic. Still farther south it decreases to 10 inches, where the Devonian rocks pass below the level of the creek. The bed thus has a thickness of 18 inches or over within a small oval area, probably little more than a mile in length and less than half a mile in breadth, and within this area it can be profitably worked.

The contour representing the thickness of 6 inches swings well to the southward between this area and that east of Swan Creek. The larger areas of the thicker portions of the bed lie to the east of Swan Creek, although the contours bend westward around a few small areas on the western side. The sections 8 to 13 represent the variations in thickness in the latter. Section 9 is on the north side of Haw Branch, and shows 10 inches of phosphate, while section 10, a short distance to the outh, shows 18 to 20 inches of compact, black, high-grade rock. The bed is here worked by the Swan Creek Phosphate Company, which has built a tramway to the Centerville branch of the Nashville, Chattanooga and St. Louis Railroad. The bed decreases rapidly in thickness toward the west, and is less than 12 inches where the Devonian rocks pass below the drainage level. On Simmons Branch the bed has a thickness of 24 to 30 inches, but shows considerable variations in character



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within short distances. It has been opened at a number of points by private parties, the rock being hauled to the terminus of the tramway on Haw Branch. The upper part of the bed is generally sandy, although at some points it is of sufficiently high grade to be utilized. Below this sandy bed are 18 to 20 inches of material having a shaly structure and containing thin streaks of conglomerate. At some points this portion of the bed yields a rock running over 70 per cent, but ordinarily it is below 50 per cent. Below the phosphate bed are from 8 to 10 inches of calcareous sandstone, also somewhat phosphatic. From this point southwestward the bed decreases in thickness to less than 6 inches within 2 miles, as shown in section 13. A little farther south it increases to 24 inches or over, and has been developed by the Tennessee Phosphate Company. The area within which the bed has workable thickness is quite small, probably forming an oval area less than half a mile in length.

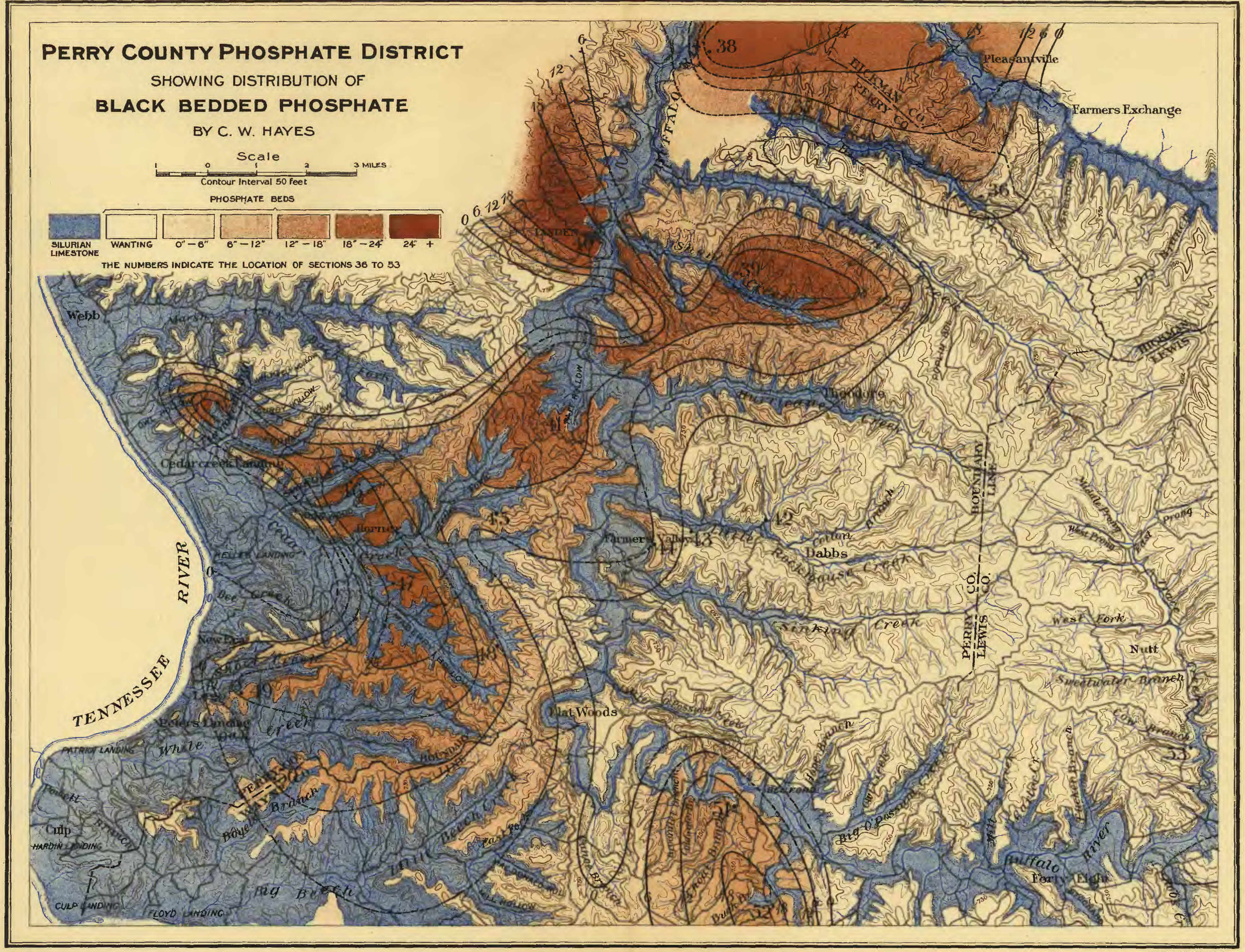
The variations in the bed on the east side of Swan Creek, from Tottys Bend southward to the Lewis County line, are shown in sections 14 to 24. The phosphate bed probably does not extend north to Duck River, but from the vicinity of the river it increases southward to Tottys Bend post-office, where it has a thickness of 30 to 40 inches. The bed is here composed of two distinct layers of about equal thickness, the upper being light gray and the lower bluish black. The former contains from 3 to 5 per cent more lime phosphate than the latter; both have a strongly marked oolitic structure. This is the location of the Duck River Phosphate Company's mines. Below the main phosphate bed there occurs a bed of phosphatic limestone, sometimes reaching a thickness of 18 inches and carrying from 30 to 50 per cent of lime phosphate.

Between the mines at Tottys Bend and Blue Buck Creek, 3 miles to the southwest, the Devonian formations are deeply covered, and it is at present impossible to say whether the phosphate bed holds its thickness of 24 inches or more across this interval, or whether the Tottys Bend mines occupy a small isolated area of thick rock. From a point near the mouth of the Blue Buck Creek for 3 miles up that stream, to the point at which the Devonian rocks pass below the drainage, the bed has a thickness of 24 inches or over, but it is nowhere of such uniformly high grade as at Tottys Bend. It has been worked by the Swan Creek Phosphate Company near the mouth of the creek, where it has a thickness of 20 to 24 inches, as shown in section 16. The upper part of the bed is rather coarse conglomerate and somewhat sandy, while the lower part is generally compact but occasionally oolitic. This region has not been thoroughly prospected, and it is probable that considerable areas of high-grade rock will be found. The black shale overlying the phosphate bed is rather thin, usually under 3 feet, and at some points contains an unusually large number of phosphatic nodules, which may be an important factor in determining the economic development of the region.

Southwest from Blue Buck Creek to Falls Branch the phosphate bed is somewhat thinner. This region comprises a considerable area between the 18-inch and 24-inch contours, but the bed in general is higher grade than that on Blue Buck Creek. As shown in section 18, on Short Creek, the bed has a thickness of 22 inches, and is composed of compact, black, high-grade rock.

Perhaps the largest productive area in which the bed has the desired thickness and quality is upon Falls Branch and a short distance to the south. On a very moderate estimate it contains at least 1,500 acres in which the bed is 24 inches or over. A large number of mines have been opened in this area by the Southwestern Phosphate Company, and the uniformly high grade of the rock has been fully proved. The thickness of the bed is shown in sections 19 to 21. Section 19, which is on Falls Branch about a mile from its mouth, and just north of the 24-inch contour, shows 18 inches of high-grade oolitic rock having a slightly shaly structure. This section is exceptional in the thickness of the black shale, which is nearly 10 feet. Resting directly upon the phosphate embedded partly within it and partly within the overlying black shales, is a layer of large phosphatic nodules. Two other layers of similar nodules occur in the black shale, while a few are found above it. This exceptional thickness of the black shale is quite local, as the mines within less than half a mile show only the normal 3 or 4 feet. Section 20, also on Falls Branch, shows a variable thickness of phosphate from 24 to 40 inches. This includes occasional lenticular beds of rather coarse conglomeratic phosphate, which occur chiefly at the top and bottom, but may occur elsewhere in the bed. The limestone floor on which the phosphate rests is rather uneven, and appears to have been somewhat eroded before the latter was deposited. Numerous large nodules occur in the overlying black shale, and also in the greensand above. That the phosphate bed holds its thickness from the upper part of Falls Branch westward at least 2 miles is shown by section 21, from Lower Pine Branch, where the bed is also worked, and has essentially the same character as above described. A conservative estimate would place the amount of phosphate to the acre in this area at not less than 7,000 tons, consequently the amount accessible from Falls Branch and Lower Pine Branch at something over 10,000,000 tons. Southward from Lower Pine Branch the thickness decreases rapidly, and within a little over a mile, as shown in section 22, it is 8 inches or less, and is very sandy. Yet farther south it increases in thickness to 24 inches or more, but still contains too large a proportion of sand for utilization. Finally, near the Hickman-Lewis county line, the bed wholly disappears, and the black shale rests immediately upon a blue calcareous shale, which contains thin lenses of chert.

On the upper part of Swan Creek, in Lewis County, are a few small areas within which the bed has a workable thickness, and these are represented in sections 25 to 35. A little south of the Lewis County


PERRY COUNTY PHOSPHATE DISTRICT
SHOWING DISTRIBUTION OF
BLACK BEDDED PHOSPHATE
BY C. W. HAYES
Scale
1 0 1 2 3 MILES
Contour Interval 50 feet
PHOSPHATE BEDS
SILURIAN LIMESTONE
WANTING
0"–6"
6"–12"
12"–18"
18"–24"
24" +
THE NUMBERS INDICATE THE LOCATION OF SECTIONS 36 TO 53
TENNESSEE RIVER
Webb
Cedar creek Landing
Pleasantville
Farmers Exchange
HICKMAN CO.
PERRY CO.
BUFFALO
Linden
Theodore
Farmers Valley
Dabbs
Rockhouse Creek
Sinking Creek
PERRY CO.
LEWIS CO.
BOUNDARY LINE
HICKMAN
LEWIS
West Fork
Nutt
Sweetwater Branch
Flat Woods
Big Opossum Creek
Buffalo River
Forty Eight
White Oak Creek
Boyd Branch
Beech Creek
Big Beech
Culp
HARDIN LANDING
CULP LANDING
FLOYD LANDING
PATRICK LANDING
Peters Landing
Brush Creek
East Prong
West Prong
Cotton
38
36
39
40
41
42
43
44
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46
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48
49
50
51
52
53

line a slight flexure in the strata brings the Devonian to the level of Swan Creek. The underlying Silurian limestone is concealed for a few hundred yards, and then again comes to the surface, forming the bottom of the valley for 8 or 10 miles farther toward the southeast. At the point where it reaches drainage level the entire Devonian, as shown in section 25, is about 2 feet in thickness. All four members, however, are present. The lowermost is represented by a few inches of cherty sandstone. Above this are 10 inches of black, sandy phosphate, then 6 inches of black shale containing phosphatic nodules, and finally an equal thickness of greensand, also containing nodules. Above the Devonian are about 40 feet of blue calcareous shale belonging to the Carboniferous. From the mouth of Little Swan Creek eastward the thickness of the phosphate bed increases rapidly to 36 inches at Weatherlys, and 18 to 24 inches at Mayfields. This area of thick rock extends nearly east and west for a distance of about 2½ miles, and is a little over half a mile in breadth from north to south. The rock is generally compact or oolitic, though in some cases the upper portion is quite sandy. It has been developed by the Tennessee Phosphate Company, and also by the Lewis Phosphate Company. The rock compares favorably in grade with that of Falls Branch and Tottys Bend.

THE PERRY COUNTY DISTRICT.

This district occupies an irregular belt extending north and south through Perry County, on either side of Buffalo River, and westward nearly to the Tennessee River. The variations in thickness of the phosphate bed are shown on the contour map, Pl. LIV, and in the sections 36 to 53. This district is separated from the one previously described by a considerable area within which the phosphate bed is not present. The Devonian rocks within the latter area are largely under cover, but the eastern tributaries of Buffalo River cut down sufficiently deep for the contour representing the extreme eastern limit of the phosphate bed to be fairly well located. As in the case of the Swan Creek district, this also consists of a number of more or less completely isolated oval areas of thick rock. By reason of the deeper dissection of this region, the outlines of these areas are better determined than in the former case.

The phosphate in this region differs quite widely in character from that in the Swan Creek district. It belongs almost, if not quite entirely, to the varieties already described as sandy or conglomeratic and shaly, while the oolitic variety is entirely wanting and the compact nearly so. Throughout the whole of the district the phosphate bed has a fairly uniform character, consisting of two distinct parts. The upper portion, generally less than a third of the entire bed, is in most cases sandy, and sometimes forms a fine conglomerate. The lower portion is always shaly, and sometimes passes into a gray, shaly, quartzose sandstone which contains but a small proportion of phosphate. The rock throughout the entire district, so far as observed, is uniformly of low grade. No considerable portions of the bed at any point will probably exceed 60 per cent of phosphate of lime, and by far the greater part will run under 50 per cent. This low grade renders the rock of this district unavailable for use in the manufacture of fertilizer at present, as it could not compete with the high-grade rock of the eastern district. There is no reason, however, why a large part of the deposit should not eventually be utilized, particularly for the manufacture of fertilizer for local use. The thickness of the bed at some points and the ease with which it can be mined and prepared for application to the soil render this local utilization probable.

Many exposures of the Devonian rocks in the upper portion of Cane Creek Valley show the phosphate bed to be entirely wanting in this region. It first appears near Pleasantville, and increases in thickness westward to 24 inches near the Hickman-Perry county line. On Brush Creek, at the point where the Devonian rocks first appear, the bed has a thickness of 3 inches, as shown in section 36, and increases westward, as shown in sections 37 and 38, to a thickness of 32 inches near Buffalo River. At the latter point the bed consists of 8 inches of conglomerate at the top, underlain by 24 inches of shaly phosphate. No part of the bed here would probably run over 50 per cent lime phosphate. South of Brush Creek the eastern limit of the phosphate bed swings far to the westward, separating this area from the next one to the south, which lies in the upper part of Short Creek Valley. As shown in section 39, the bed here has a thickness of 20 inches, and consists of a layer of conglomerate at the top and shaly phosphate below.

The next area showing a considerable thickness is on the west side of Buffalo River at Linden. The western limit of this area is not known. The bed here has a thickness of 20 inches, made up of 6 inches of conglomerate at the top and 14 inches of shaly phosphate below. As shown in section 40, the phosphate bed is here underlain by a considerable bed of gray sandstone. This sandstone extends some distance to the northeast, but is only a few inches in thickness on Brush and Cane creeks, and wholly disappears toward the head of the latter. South and southwest from Linden this sandstone bed is quite constant, with a thickness of 3 or 4 and sometimes 6 feet, and forms an important stratigraphic and topographic horizon, giving rise to a terrace about the valley sides.

South of Linden the phosphate bed decreases rapidly in thickness, and within a mile entirely disappears. Two miles south of Linden it reappears and rapidly increases to 18 inches, which thickness it retains over a considerable area lying mostly west of Buffalo River. As shown in section 41, it has essentially the same character as at Linden. A short distance east of Buffalo River, on Rockhouse and Sinking creeks, the phosphate bed entirely disappears, and also the black shale, as shown in section 42. The Devonian here consists of only two members, the lower and upper, the bed of gray sandstone about 6 feet in thickness, upon which rests the bed of greensand, containing a few phosphatic nodules.

The region west of Buffalo River, drained by streams flowing to the Tennessee, is deeply dissected, and the Devonian rocks, with the overlying Carboniferous are removed from considerably more than half the area. Two small areas of thick phosphate are found in this region. The first and largest extends across various branches of Cedar Creek from Swindell southwest to Maberry branches. As shown in sections 46 and 47, the phosphate bed is over 30 inches in thickness. It is in general sandy or conglomeratic at the top and shaly in the middle and bottom portions, but it is here less sharply divided than is the case in the vicinity of Linden and elsewhere. It shows considerable variety in composition. Some of the shaly beds have much the appearance of the compact phosphate of Swan Creek, others approach the black shale in composition, containing a very large proportion of carbonaceous matter, while still others are merely a more or less phosphatic, fine-grained sandstone. It is quite possible that the bed may be found at some points to contain a considerable proportion of 60 to 65 per cent rock, but the average of the whole bed throughout considerable areas will undoubtedly go below 50 per cent. A small area on Furnace Branch of Cedar Creek shows an exceptional thickness of 60 inches or more. The bed is poorly exposed, and an exact measurement could not be obtained. It has the same character as that shown in section 46, and probably contains considerable medium-grade rock.

Southward from Cedar Creek, upon Short and Whiteoak creeks, the bed decreases in thickness, and at many points runs into a gray shaly sandstone, which probably contains a very small proportion of phosphate. Returning to the valley of Buffalo River, in the northern part of Wayne County, the phosphate bed reappears, but is thin and extremely sandy, as shown in sections 51 and 52. At some points it more closely resembles the underlying gray sandstone than the true phosphate. A little farther toward the southeast, on Forty-eight Creek, beyond the limits of the map, there is a small area in which the bed has a thickness of 24 inches or more and in which the phosphate is much better than the average in Perry County. At some points the entire bed of 20 to 26 inches will probably average as high as 55 per cent lime phosphate. In the region drained by the upper part of Buffalo River and its tributaries the phosphate bed is entirely wanting, as well as the black shale, and the underlying gray sandstone also decreases in thickness, so that at some points the entire Devonian section is represented by the thin bed of greensand with a few phosphatic nodules. In the vicinity of Riverside and Mannie the phosphate bed is represented by a few inches of black sandstone, which is probably only slightly phosphatic.

ORIGIN OF THE BLACK PHOSPHATES.

The origin of the several varieties of black phosphate was considered in the previous report, above referred to, and the more detailed study of the region confirms the conclusions there stated, namely, that they are due to the slow accumulation of phosphatic organisms on the sea bottom, and now have essentially the form in which they were originally deposited.

There can be no question that a broad unconformity exists between the Silurian and the Devonian formations in the entire southern Appalachian province, but detailed examination has failed to reveal evidence in this particular region of marked local unconformities, such as discordance in stratification or the inclusion of fragments of the lower formations in those later deposited. The theory that the absence of the upper Silurian and lower Devonian formations in the Tennessee region, at least, is due not to the existence of a land area and subaerial erosion, but rather to nondeposition, by reason of strong marine currents, is strengthened both by positive and by negative evidence. Whatever may have been the cause of the nondeposition in late Silurian and early Devonian times, however, it was followed by a long period of extremely slow deposition covering a large portion of the Devonian.

The extremely small amount of foreign detrital matter brought in during Devonian time apparently came from the southwest, probably from a land area in the Arkansas region, where there are indications of subaerial erosion of the lower Paleozoic formations. Recalling the detailed account of the character of the phosphates given above, it will be noticed that not only does the lower member of the Devonian, the sandstone bed, increase in thickness toward the southwest, but also that the proportion of detrital quartz in the phosphate bed increases in the same direction. That deposition during this period was extremely slow is shown by the fact that the accumulation of a few feet, or in some cases inches, of rock in this region corresponds in time with the deposition of many hundreds or even thousands of feet in the northern Appalachians. These few inches of rock can be traced northward with gradually increasing volume into the thicker Devonian formations of Kentucky and Ohio, and there is no reason to believe that they correspond to a single bed in the latter region rather than to the whole.

Following the deposition of the Silurian limestone, conditions which before had been favorable for the growth and accumulation of the calcareous organisms suddenly changed, and the formation of limestone ceased. The conditions then became favorable for organisms whose tests contained a considerable proportion of phosphate of lime. These tests accumulated upon the sea bottom, their calcareous portions were removed by solution, and a certain amount of replacement of carbonate by phosphate took place. Much of the phosphate may have been in the form of a gelatinous precipitate forming an ooze upon the sea bottom, and this by segregation formed the phosphatic ovules already described. Mingled with this phosphatic mud were the bones and teeth of the Devonian fishes which flourished in the seas of the region, and which doubtless furnished a considerable portion of the phosphoric acid contained in the bed. The sea in which this deposition was going on was probably comparatively shallow. That there were currents of sufficient strength to move pebbles upward of an inch in diameter is certain, and the distribution of the phosphate bed is most readily accounted for by the supposition that there were irregular currents and eddies which accumulated the phosphatic mud in certain places and removed it from others. If the water had been deep and free from currents the phosphate bed would have been much more evenly distributed than it is.

Following the period in which conditions were most favorable for the accumulation of the phosphate was a period in which a small amount of clay was introduced into the region, together with a large amount of carbonaceous matter, very probably derived from seaweeds. These conditions gave rise to the deposition of the black shale. The sea bottom must still have been swept by currents, for in certain areas no deposition of the black shale took place. Organisms secreting phosphate of lime were still somewhat abundant, and the phosphate secreted by them was probably at first disseminated through the carbonaceous mud, and later became segregated, and formed the phosphatic nodules that occur at various points in the black shale.

A change of conditions terminated the deposition of this carbonaceous mud and inaugurated the formation of the overlying greensand. The conditions favorable for the formation of glauconite are fairly well understood. They involve a moderate depth of water and a moderate supply of detrital material, derived in most cases from the disintegration of crystalline rocks or rocks containing a considerable proportion of the alkalies, particularly potash. During the formation of the greensand the force of the currents was checked and the deposit was spread with remarkable uniformity over a very large area. Phosphate-secreting organisms were universally present, and their remains, at first disseminated and afterwards concentrated, formed the phosphatic nodules which everywhere occur in the greensand.

The passage from this uppermost Devonian bed to the overlying Carboniferous is generally abrupt, but everywhere conformable. The transition marks a sudden and complete change in the conditions of the sea. There was an invasion of foreign detrital material, largely the finest clay silt, and a cessation in the formation of glauconite, while the organisms secreting carbonate of lime and silica became dominant and a great thickness of calcareous cherty shale was deposited.

It is thus seen that in this region the history of an extremely long period, at least a large part of Devonian time, is compressed into a very brief record. It is a question whether the phosphate-secreting organisms were more abundant during this period than before or since. Conditions may have been slightly more favorable for their growth at that time than in other periods, but the factors determining the accumulation of the high-grade phosphates were more probably the absence of foreign detrital matter and the presence of currents of such character that the calcareous organisms deposited at the same time were dissolved, and thus removed, so that the phosphatic organisms which would normally have been disseminated through a great thickness of strata, as they doubtless were elsewhere, were here concentrated into the narrow compass of a few inches.

II. WHITE PHOSPHATES.

The white phosphate of Tennessee was first described by the writer in a paper read before the American Institute of Mining Engineers in 1893. This paper was the result of observations made during a brief visit to Perry County in the fall of 1894. Two types were distinguished—the breccia and the bedded phosphate. They appeared to have such different characteristics that they were placed in distinct classes, their formation being ascribed to different conditions. The region to which these two varieties appear to be confined was revisited in the fall of 1895, and more thoroughly examined. As a result of this further examination the first classification is somewhat modified. The two varieties are found to be much more nearly related than was at first supposed, and they are found grading into each other imperceptibly, so that the distinctions supposed to exist disappear on more careful examination. Also, it is found that the same process to which the formation of the breccia was ascribed will account for the formation of all the varieties, simply assuming slight differences in the surrounding conditions. This being the case, the distinction at first made will be dropped, and the white phosphate will be described as a group of slightly different varieties.

ASSOCIATED CARBONIFEROUS ROCKS.

The white phosphate, whatever may have been its original source, is now undoubtedly altogether secondary. It is intimately associated with Carboniferous rocks, and some account of these rocks is necessary to an understanding of the character and origin of the phosphate. About 250 to 300 feet of Carboniferous rocks occur in this region.

Resting on the thin layer of greensand which forms the upper member of the Devonian formation is black, shaly, siliceous limestone containing scattered nodules of chert. Passing upward the latter increase rapidly in numbers, and 15 feet above the base are replaced by beds of black chert embedded in dark-blue siliceous limestone. In the lower 75 feet the chert nodules and layers make up from 20 to 40 per cent of the mass of the formation. Above this for perhaps an equal distance the well-defined plates and nodules of chert are less abundant, although there is probably no diminution in the proportion of silica in the rock. Instead of being in well-defined masses, however, it is only partially segregated, and merges into the more calcareous portions of the rock without definite boundaries. This form is not compact, translucent chert, breaking with conchoidal fracture, but has a stony structure, and breaks with a rough, uneven surface. On weathering, it splits up into irregular lens-shaped pieces from one-half inch to 1½ inches in thickness, giving its exposures a shaly appearance.

The upper part of the formation shows an increase in the segregated silica, chiefly as chert nodules, although thin plates also occur. The rock in which these are embedded is a purer limestone, and on weathering gives rise to some red soil. It probably passes upward without abrupt transition into a rather pure blue limestone with little chert. This higher formation has been wholly removed from this region.

All parts of this formation weather by the solution of the calcareous portions, leaving the chert free to form a deep mantle of residual surface material. The upper and lower portions yield the largest proportions of residual material, but by surface creep all parts of the formation are deeply covered, except where the slopes are too steep for loose material to lie. It will readily be seen that the material resulting from the weathering of these rocks will be porous and favorable for the percolation of surface waters. Where the chert is in the form of nodules and thin plates it is broken into small fragments by the changes in position consequent on the solution and settling, so that none of its original structure remains. Where the chert beds are abundant and heavier they settle down with more or less breaking as the lime is removed, but retain, to some extent, their original horizontal position, leaving many crevices through which water may flow. Finally, when the silica is only partially segregated, there remains, after weathering, a spongy skeleton of silica which is soft below the surface and generally crumbles to a siliceous soil, the spongy mass readily breaking down when exposed at the surface.

The Tennessee white phosphate, as stated on a preceding page, may be conveniently classed in three varieties—(1) stony, (2) lamellar, and (3) breccia. The origin of the differences between the varieties will be pointed out later, in discussing the origin of the phosphate and its method of accumulation.

STONY PHOSPHATE.

This variety was described in the previous report as "white bedded phosphate." The name now given it appears more suitable, as the former one might lead to a misconception regarding its extent, by implying that the rocks had the same mode of occurrence as the black bedded phosphate described in the preceding part of this report. This variety occurs in more or less regular bands, alternating with somewhat thinner bands of stony chert. These interbedded cherts are precisely similar to the stony chert beds which occur in the middle portion of the Carboniferous rocks, as explained on a previous page, and the phosphate bears to them the same relation as the siliceous limestone to the interbedded chert. It passes gradually into the chert without sharp break or definite line of transition. It is much harder than ordinary lime phosphate, and breaks with an extremely rough, irregular surface. It has a finely granular structure, some portions resembling a very fine quartzitic sandstone, but also grading into translucent chert. The patches of gray chert surrounded by the white granular rock give a mottled appearance to the fresh surfaces. The chert is not in the form of sharply defined fragments, such as occur in the phosphate breccia, but merges into the granular groundmass, which consists of a skeleton of silica holding soft white lime phosphate. It is the presence of this siliceous skeleton which gives the apparently granular material its great hardness. Many small, irregular cavities occur in the rock, and these are generally lined with minute quartz crystals.

Thin sections of the phosphatic rock exhibit under the microscope a more or less continuous groundmass of chalcedonic or cryptocrystalline silica, embedded in which are rhombohedral crystals. In portions of the rock which appear as compact chert they are very minute (often less than one one-hundredth millimeter in diameter) and widely scattered, but perfect, sharply defined rhombohedrons. In the granular portions of the rock the crystals are larger, appearing as sections of rhombohedrons, which are not perfectly independent, but are segregated into irregular groups, surrounded and penetrated by the groundmass of silica. These rhombohedral crystals have the external form of calcite, but are entirely isotropic, and hence are not calcite. The smaller crystals are quite clear and transparent, while the larger are composed of an aggregate of very minute transparent grains, with fine, dust-like, opaque particles, probably iron oxide. Many aggregates of similar transparent grains, but without definite crystal outlines, occur in the groundmass. Analyses of the rock make it evident that the material forming the crystals and the granular aggregates must be lime phosphate. The crystal forms are evidently those of calcite, and the crystals are therefore, in all probability, pseudomorphs, in which the lime phosphate has replaced the carbonate. The presence of a small amount of carbonate, shown in the table of chemical analyses below, indicates that the replacement has not been complete.

CHEMICAL COMPOSITION.

The following analyses[1] give a fair idea of the composition of this variety of phosphate:

Analyses of Tennessee white stony phosphate.

	14*c*.	14*i*.	14*k* and *l*.	14*m*.	15*d*¹.	15*d*².
Silica, SiO_2	61.34	49.43	54.30	54.88	50.18	56.46
Lime, CaO	20.30	26.40	22.87	22.76	25.57	22.01
Phosphoric acid, P_2O_5	12.55	15.12	14.86	15.30	15.21	13.15
Corresponding to:						
Lime phosphate, $Ca_3P_2O_8$	27.40	33.00	32.45	33.40	33.20	28.60
and						
Lime carbonate, $CaCO_3$	9.75	15.21	9.36	8.23	13.45	11.56

14*c*.—Stone Quarry Hollow, south of Terrapin Creek. Phosphate and chert 2 feet from base of exposure; represents a bed 8 inches thick between thinner beds of chert.

14*i*.—Stone Quarry Hollow. Represents the upper 10 feet of the deposit, above the interbedded chert and phosphate.

14*k* and *l* —Stone Quarry Hollow. Represents 10 feet of outcrop, 20 to 30 feet above its base.

14*m*.—Stone Quarry Hollow. Represents 6 feet of outcrop, 30 to 36 feet above its base.

15*d*¹ *and* 15*d*².—*Red Bank Creek, Spencer place.* Represents *upper 10 feet of the deposit, from* 20 to 30 feet above the base of the exposure.

Only the silica, lime, and phosphoric acid were determined; but in each case there was an excess of lime over that required for combination with the phosphoric acid to form the neutral phosphate, and this excess was regarded as present in the rock as carbonate. Considering the lime as part carbonate and part phosphate, the proportions of these compounds, together with the silica, amount to from 96 to 98 per cent of the rock. The remaining 2 to 4 per cent is probably iron and alumina, which were not determined.

BRECCIA PHOSPHATE.

This is perhaps the most abundant variety of the three, and the one possessing the greatest interest from an economic standpoint. It occurs in irregular masses composed of small, angular fragments of Carboniferous chert embedded in a matrix of phosphate of lime. The chert fragments vary in diameter from a fraction of an inch to 3 or 4 inches. They are in all respects similar to the fragmental chert which has weathered out from the overlying siliceous limestone and forms a deep mantle upon the hillsides. In some cases, where the chert beds were unusually abundant in the limestone, they were not broken up and

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[1] Analyses made for the United States Geological Survey by the chemical department of Columbian University, Washington, D. C., under the direction of Prof. C. E. Monroe.

transported to a distance when the lime was removed by solution, but settled down with more or less fracture and contortion in approximately their original horizontal position. In such cases the chert blocks are generally large, and even when cemented by the filling of the interstices with phosphate the resulting rock can scarcely be called a breccia. The phosphatic matrix, when unstained by exposure to the weather, is generally white or slightly reddish and rather soft, somewhat harder than compact chalk. When taken from a few feet below the surface, where it has not been exposed to the air, it is easily crushed and the chert separates, so that but little phosphate adheres to it. When exposed to the air for a long time, the matrix weathers out to some extent, leaving the chert projecting from the surface, while that which remains becomes indurated and forms a strong cement about the included chert. Hence, in the weathered exposures the chert is more prominent than the phosphate, and it is difficult to make a clean separation of the two components of the rock.

The breccia phosphate is found associated with the stony variety in a few cases, as at Spencers Bluff, to be described later. It also, in some cases, shows a gradation into the next variety, particularly when the chert occurs in large blocks which retain somewhat their original horizontal position.

LAMELLAR PHOSPHATE.

This variety, as its name implies, consists of thin parallel layers or plates. It has evidently been formed by deposition from solution, successive layers being slightly different in color and texture. In numerous cases the deposition seems to have taken place in a rather smooth cavity, which was but partly filled with the depositing solution, so that deposition took place only on the bottom. At first compact material chiefly was deposited, varying in color in different layers from white or yellow to deep red; later, the material became more spongy and porous and the layers less even. Finally, on the upper, irregular surface a thin layer of transparent phosphate was deposited, leaving a rounded or mammillary surface. These plates are often several inches broad and the compact portion generally less than an inch in thickness. Subsequent to their formation the plates were sometimes broken and recemented, making a breccia in which both matrix and fragments are composed of lime phosphate.

This lamellar variety appears to be less widely distributed than the other two. This may be due to its having been formed under peculiar conditions which were less prevalent than those under which the other varieties formed, or to the fact that it is less apt to be discovered without careful and systematic search, and hence has a wider distribution than at present known. The latter reason seems to be more probable, considering the character of the material and the ease with which its outcrops might be covered by the more durable chert creeping down from the higher slopes.

It occurs in some cases in rather large masses, several feet in diameter, composed of more or less brecciated and recemented plates. More often the broken plates are found mingled with the clay soil, together with some loose fragments of chert. The plates are also found, evidently in the position in which they were formed, partly or wholly filling the crevices among the larger blocks of chert which have weathered out so as to remain nearly horizontal.

DISTRIBUTION OF THE WHITE PHOSPHATE.

So far as at present known, the white phosphate is confined exclusively to Perry County. It occurs in isolated deposits, which, however, are generally grouped within small areas. The two districts which contain the largest number of these deposits are, first, in the northern part of the county, on Red Bank and Terrapin creeks; and, second, in the western part, on Toms Creek. In addition to these groups of deposits there are several which appear to be entirely isolated. Two of the latter are near Buffalo River, in the vicinity of Beardstown, and a third is on Lick Creek, south of the Toms Creek district.

These deposits will now be described in detail.

TERRAPIN CREEK DISTRICT.

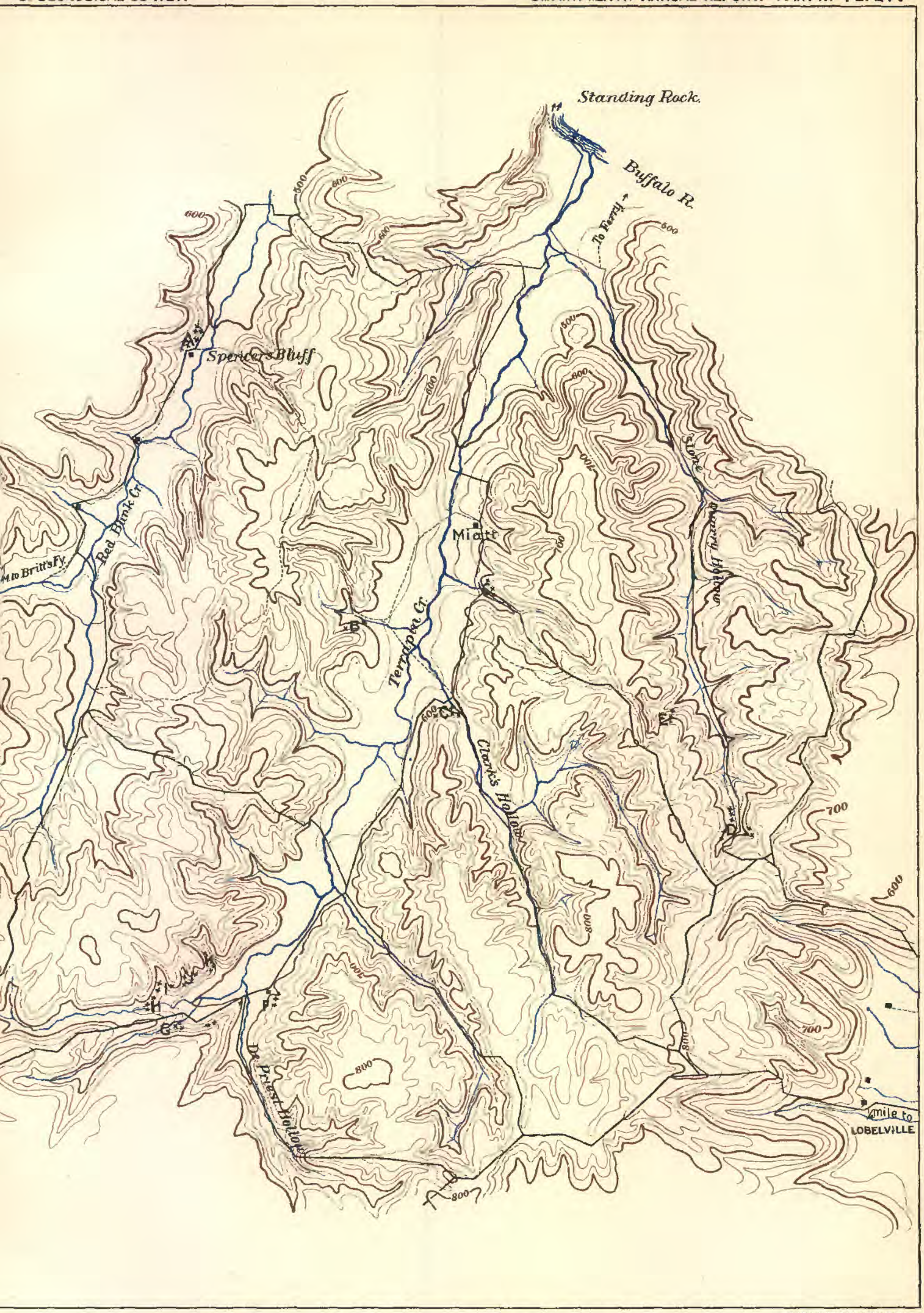
This district, as represented on the accompanying map, Pl. LV, embraces about 12 square miles in the northern part of Perry County. The northernmost deposit of phosphate in this district is at Spencers Bluff, on Red Bank Creek, at the point A on the map. Two varieties occur here intimately associated, namely, the breccia and the stony phosphate. The latter variety makes up the greater part of the natural exposure. It forms a bluff along the west side of the valley for a distance of about 50 yards. This bluff is from 20 to 30 feet high, the lower portion being much the steeper. The lower 20 feet consist of alternate beds of stony phosphate and chert. The latter appears in lenticular layers from 4 to 12 inches in thickness, its contact with the phosphate being somewhat indistinct. None of it approaches the translucent varieties of chert in appearance, but it has a dull-gray aspect and a granular structure, more nearly approaching quartzite than chert. These beds make up from 20 to 40 per cent of the lower part of the bluff. The remaining beds are much whiter and softer than the chert, and consist of siliceous phosphate of lime. These phosphate layers are not uniform in composition, but some portions are much more siliceous than others. The siliceous portions are not inclusions of chert such as occur in the breccia, as their outlines are indistinct. They correspond very closely with the imperfectly segregated, siliceous concretions in the Carboniferous limestone already described. The upper 10 feet of the bluff has a more gentle slope, and the underlying rock is less perfectly exposed than in the lower portion. It is to a considerable extent covered with soil and residual chert from the higher portions of the hill. This portion evidently contains fewer beds of chert than the lower part, and hence offers less resistance to erosion and is more rapidly worn down. All of the beds exposed are composed of white phosphate, having a much more uniform composition than the lower beds—that is, the silica which they contain appears to be more evenly disseminated throughout the mass.

No opportunity was afforded to determine the horizontal or vertical depth to which this phosphate extends. If the conclusion is correct that it is due to the substitution of calcium carbonate by calcium phosphate in a siliceous limestone, it is not probable that the deposit has a very great extension in either direction beyond that which appears in the natural exposure.

A short distance to the north and a little farther up the hill slope is a considerable deposit of breccia phosphate. Fragments of the rock are found upon the surface over a considerable area. This point of the hill has been used as a burying ground, and in digging the graves some unintentional prospecting has been done which gives a better idea of the amount of phosphate than could have been obtained by examination of the surface alone. Indeed, except for this, the presence of the phosphate might easily have escaped attention. The few fragments which occur at the surface closely resemble the residual chert and would easily be overlooked. It is found that, a short distance below the surface, there occurs a practically continuous layer of the breccia. This is only partially consolidated and can be readily removed with a pick and shovel. It contains a large proportion, perhaps 50 per cent, of angular chert fragments. The cement in which these are embedded is soft and friable and separates easily from them. It is difficult to make any estimate as to the quantity of this rock contained in this deposit. As already stated, little or no indication of its presence is afforded by surface outcrops, and there are no means of determining its extent except by careful and systematic prospecting.

Occurrences of the stony phosphate have been reported from various localities south of Spencers Bluff, on Red Bank Creek and its tributaries, but no indication was found in support of these reports. It is possible that in all cases the beds of chert in the siliceous limestone have deceived the inexperienced prospectors.

The next deposits to be described form a small group about 2½ miles southeast of Spencers Bluff, on Terrapin Creek. This is locally known as the "Miatt place." On the west side of the creek, at the point B on the map, in a narrow tributary ravine, the stony phosphate forms a bluff somewhat similar to the one above described, but less extensive. The greater portion of the rock exposed resembles the upper and less siliceous part of Spencers Bluff. Some of the beds on weathering form a somewhat porous or spongy rock, owing to the phosphate which had filled the cavities in the siliceous skeleton being much softer and sometimes partially removed. This siliceous skeleton is extremely hard, and somewhat resembles French buhrstone. In the early days it was



RED BANK AND TERRAPIN CREEKS.

Showing Location of White Phosphate Deposits.

Scale.

0 ½ 1 2 miles

Contour interval 25 feet.

used for millstones, and several stones blocked out and partially dressed mark the site of the industry at this point.

On the opposite side of the valley, at the point C, there are several rather extensive exposures of the phosphate. Its thickness is shown in one place to be at least 30 feet. The bedding here is less distinct than at Spencers Bluff, and the character of the rock from top to bottom is nearly uniform. Intimately associated with the stony phosphate at this latter point are some deposits which resemble the breccia, although the distinctions between the inclusions and the matrix are less sharp than is usually the case.

In the same direction toward the southeast, and about the same distance as that from Spencers Bluff to the Miatt place, there is a third group of deposits in Stone Quarry Hollow and some of its tributary ravines. The phosphate is best exposed at the point D on the west side of the road, where it is at least 40 feet in thickness. As at Spencers Bluff, the lower portion consists of alternating layers of stony phosphate and chert, while the upper part is made up largely of phosphate, but is much less perfectly exposed. Another small exposure occurs at the point E, about half a mile north of the last, and it is possible that the phosphate is continuous from one to the other. Here, also, primitive millstones were made, and this branch of Terrapin Creek took its name from the quarry in which they were obtained.

About 2 miles southwest of the Miatt place, near the head of Terrapin Creek, is another group of deposits, perhaps the most extensive one in this district. No single exposure is so extensive as that at Spencers Bluff, but the outcrops of the rock are seen at intervals over a much larger area. They occur at the mouth of De Priests Hollow, at the point F, and on both of the head branches of Terrapin Creek, G and H, and in several of the ravines along the west side of the valley, I, J, and K. At least a dozen exposures were observed in this group within a radius of a quarter of a mile. By far the larger part of the rock in this vicinity corresponds closely in composition with that in the upper part of Spencers Bluff, although some poorly defined breccia was also seen. The relation of the stony phosphate to the siliceous Carboniferous limestone is well shown in this region. Unusually good exposures of the latter occur along the sides of the ravines, and it is sometimes found within a few yards of the phosphate ledges and at the same horizon. From the nature of the exposures it was impossible to find an actual passage from one rock into the other, although it seems practically certain that such a passage actually takes place and could be observed in an artificial cut. These numerous deposits within a small area at the head of Terrapin Creek suggest original continuity. It seems probable that there may have been at one time a single body of the substituted rock, which has subsequently been dissected by the various branches of Terrapin Creek, so that only small portions of the original body remain.

Another deposit of the stony variety of phosphate occurs about 3 miles south of Lobelville and a mile west of Buffalo River. It is about

100 feet above the river valley, near the top of a sharp point of land between two ravines. The deposit must be quite small, since the siliceous limestone is exposed a short distance back in both ravines. Between the phosphate and the limestone, cutting across the narrow point, is a well-defined vein of limonite containing many inclusions of chert. Other thin veins of limonite are seen cutting the siliceous limestone at various angles.

TOMS CREEK DISTRICT.

Toms Creek is in the northern part of Perry County, flowing westward into the Tennessee River. At two points in its valley considerable deposits of white phosphate have been discovered. Their location is shown on the accompanying sketch map, fig. 44. The easternmost of these localities is a short distance above the main division of the stream upon the north branch. The deposits occur on the Cotton place and adjacent properties. They are confined to the northwest side of the valley and are distributed through a distance of about half a mile, following the windings of the valley side around the heads of the

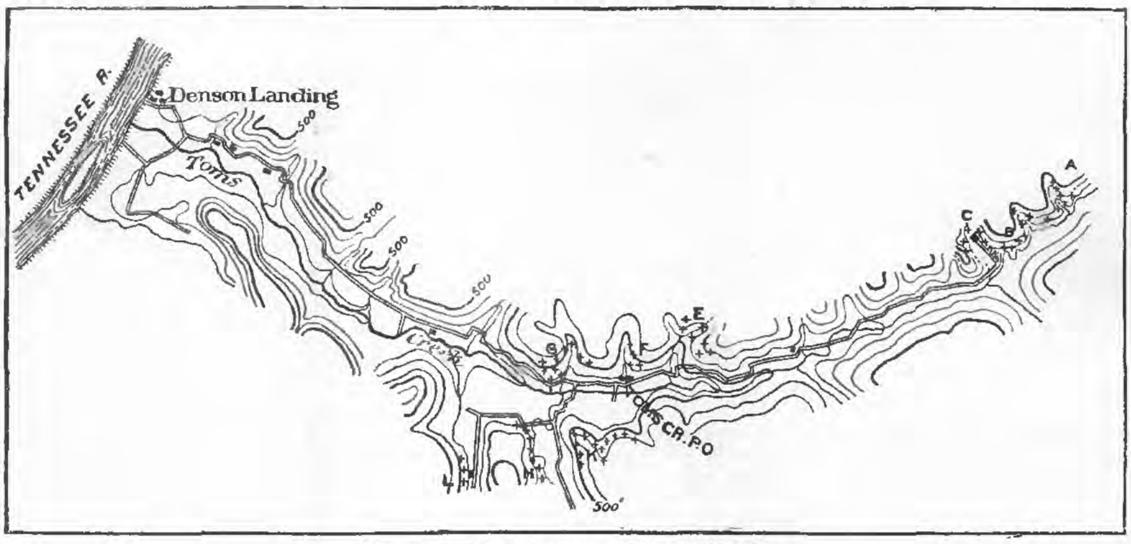


FIG. 44.—Sketch map of Toms Creek.

smaller ravines. The exposures are by no means continuous through this distance, but the extent of the deposits is indicated by occasional fragments on the surface, as well as by larger outcrops forming considerable bluffs. The phosphate appears to be confined to 30 or 40 feet in vertical range. It is not found in the bottom of the valley nor on the tops of the spurs.

The phosphate in this locality consists entirely of the breccia variety, although there is some which approaches the lamellar, but nothing resembling the stony variety. At some points, particularly in the northeastern of the three ravines in which the deposits occur, at the locality marked A on the map, the phosphate forms the matrix of a very coarse breccia. The silica in the original limestone was evidently well segregated, so that the original formation consisted of a tolerably pure limestone in which were embedded many thin beds or plates of chert. Upon the solution of the lime the chert beds settled down with little change from their original horizontal positions, but with considerable fracture and minor dislocation. The numerous cavities between these blocks of chert are partially filled with lime phosphate, which generally shows a lamellar structure, having evidently been deposited in successive bands from solution. Wherever the chert is broken up into finer fragments and the interstices are completely filled with lime phosphate this matrix is granular and softer, showing no banded structure. It seems probable that these chert beds were derived from the base of the Carboniferous rocks, although the underlying Devonian could not be seen.

A little farther toward the southwest, at the point B, along the sides of a spur between two ravines, the phosphate shows at intervals for a distance of nearly a quarter of a mile. It was not found forming a ledge, but in patches, which are apparently the remnants of bodies formerly much more extensive. The phosphate is entirely a breccia containing rather small fragments of chert embedded in the structureless matrix. It is found in many cases resting directly upon the underlying Silurian limestone. Whether it was formed in this position or has been subsequently dropped down by the solution of the limestone can not be determined. The latter, however, is the more probable. One exposure of the Devonian rocks occurs closely associated with this phosphate. It is at the head of the ravine, at the point C on the map, and at a little higher altitude than the exposure of the phosphate. It consists of about 6 feet of typical black (Chattanooga) shale, below which are a white sandstone and a few inches of blue clay, evidently a weathered shale. Above the black shale is a greenish clay containing a few phosphatic nodules. These were originally black, but are weathered to light gray, and much of their substance has evidently been removed by solution.

The second locality on Toms Creek is about 3 miles west of the one above described, near Toms Creek post-office. The phosphate deposits occur chiefly upon the Leadbetter place and the immediately adjoining properties. They are found on both the north and south sides of the creek, and, as above described, follow the winding of the bluffs about the heads of the minor ravines. The deposits seem to be about equally divided between the breccia and the lamellar varieties, although the former make the larger showing at the surface by reason of their greater capacity for resisting erosion. In the head of a ravine on the north side of Toms Creek, at the point E on the accompanying map, the phosphate occurs in a number of large bowlders, the deposit being apparently 8 or 10 feet in thickness. It consists entirely of breccia, made up of very small fragments of chert embedded in a small amount of lime phosphate matrix. The Silurian limestone is seen in a place about 15 feet below the phosphate.

On the point of a spur, at the locality marked F on the map, the phosphate is seen in numerous irregular masses from 3 to 6 feet in diameter scattered about the surface, and also embedded in clay containing numerous fragments of lamellar phosphate and chert. The proportion of the two constituents in the breccia is quite variable. In some cases the chert makes up as much as 75 per cent of the mass, and in others it is perhaps less than 10 per cent. The blue fossiliferous Silurian limestone is seen outcropping at various points in the immediate vicinity of the phosphate and at the same horizon.

A little prospecting has been done at this point, and shallow trenches have been dug, but nothing in a systematic manner or sufficient to show to what depth the phosphate extends. It shows, however, that the phosphate matrix of the breccia is much softer a short distance below the surface than where it has been indurated by exposure to the air; also that a large amount of phosphate, chiefly the lamellar variety, which gives no indication of its presence at the surface, is embedded in the clay.

It seems not altogether improbable that this fragmental phosphate, disseminated through the clay, may prove the most important variety from an economic standpoint.

At a somewhat lower level than the deposit last described, the phosphate is found at the point G on the map; also in large, irregular masses of breccia resting directly upon the Silurian limestone or embedded in the clay and chert It extends a short distance above the road and covers the surface more or less abundantly 30 feet below the road to the level of the creek. From surface indications it appears that this particular deposit covers an area of about 75 by 100 feet. It also occurs at various points on the sides of the adjacent ravines.

On the opposite side of Toms Creek from the last-described locality occur perhaps the most extensive deposits in the entire district. Almost continuous indications of its presence are found for a distance of nearly half a mile. Especially good indications are seen on the west side of a small tributary which joins Toms Creek at this point, marked H on the accomanying map. The phosphate at this point is almost entirely of the lamellar variety. It occurs both in large blocks, made up of the compact banded plates which have been themselves more or less brecciated and recemented by a phosphate matrix, and in similar banded plates disseminated through the residual clay. A little prospecting has also been done here, but not enough to satisfactorily test the quantity of the rock. Except for the fact that this tributary of Toms Creek has cut into the side of its valley, exposing a steep bluff, these deposits would afford little or no indication of their presence at the surface.

For some distance along the bluff which forms the south side of Toms Creek Valley, marked K, a coarse breccia forms considerable ledges. Whether the lamellar variety also exists here can not be told without prospecting, but it would probably be found in greater or less amount associated with the breccia.

Finally, at the point L, there is a small exposure of the breccia containing rather a large proportion of chert.

ORIGIN OF THE WHITE PHOSPHATES.

From the nature of the deposits of white phosphate, their relations to other formations of the region, and the physical characteristics of the several varieties of the rock, there can be little doubt as to their mode of deposition. It seems reasonably certain that the rock is entirely a secondary deposit, accumulated subsequent to the deposition of the Carboniferous, Devonian, and Silurian formations, with which it is now associated. The latter were laid down on the sea bottom as horizontal beds of sand, mud, and shells, having great lateral extent. They were buried beneath other beds of sediment many hundred feet in thickness, which have since been removed by erosion. The black phosphate, as has already been explained, is one such sedimentary bed which was deposited when the conditions were favorable for the accumulation of lime phosphate on the sea bottom. It was afterwards deeply buried by later-deposited sediments, and has been brought to light by elevation of the sea bottom and erosion of the overlying strata.

Entirely different is the formation of the white phosphate. The lime phosphate of which these deposits are composed was doubtless originally extracted from sea water by organisms, and accumulated along with other sediments, either segregated in beds and concretions or disseminated through limestones and shales. When these rocks were brought near the surface by uplift and erosion they were attacked by percolating surface waters, which contain carbonic and other organic acids. These acids readily dissolve carbonate of lime, and to some extent also phosphate of lime. When water which has slowly percolated through the rocks at some depth emerges at the surface or into a cavity in which it is no longer subjected to pressure, the excess of carbonic acid escapes, and the substances which had been held in solution by means of that acid may be redeposited. Thus many springs are now forming about their exits extensive deposits of materials which they had dissolved in the course of their underground passage. The most common spring deposits are calcareous, although siliceous and aluminous deposits are not uncommon, particularly in case of thermal waters. When several substances are held in the same solution the least soluble will generally be the first to separate, and hence will form deposits nearest the exits. Also, when a solution of a difficultly soluble substance, as lime phosphate, comes in contact with one which is more easily soluble, as lime carbonate, there is generally an exchange effected—the more soluble substance is taken up and the less soluble one is deposited in its place.

A simple application of these principles suggests the probable mode of formation of these deposits. The altitude at which they are found indicates that they were formed when the valleys of the region had about two-thirds their present depth. The region was probably heavily forested, the decay of vegetation furnishing an abundant supply of organic acids to the percolating surface waters. It was also a region of sluggish streams, the valleys of which may have been to some extent occupied by swamps. The waters, thus highly charged with organic acids, descending through the more or less porous formations which occupy the higher portions of the country, dissolved calcium carbonate, and in less quantity calcium phosphate. The former, by reason of its greater solubility, was carried into the streams and thence to the sea. The phosphate, however, was deposited, the form of the deposits being modified by local conditions. In some cases the waters containing these substances in solution found an outlet in a mass of fragmental chert derived from the decay of the overlying formations. Under such conditions the breccia was formed, the phosphate merely cementing the fragmental material. In other cases the waters flowed through open cavities of considerable size. When these were the interstices among blocks of chert, there resulted the coarse breccia. The cavities were wholly or in part filled with compact phosphate, which shows, by differences of texture and color, that it was deposited from solution in successive layers. In some cases it appears that the cavities were in a pure limestone. After they had been to a greater or less extent filled by the phosphate, by reason of some change in conditions, the limestone was dissolved, leaving the phosphate disseminated through the residual clay, which represents the original insoluble constituents of the limestone. Finally, in some places, instead of finding open cavities in which the phosphate might be deposited, the solution, before emerging at the surface, came in contact with a siliceous limestone under conditions such that a transfer of materials was effected. The more soluble carbonate was taken up and the less soluble phosphate was deposited in its place. These conditions gave rise to the stony variety, in which the phosphate is clearly seen occupying the place originally held by the carbonate.

If this explanation of the origin of these phosphates is the correct one, some important economic conclusions follow as to the extent of the deposits. So long as the waters were percolating slowly and at considerable depths they would take up rather than deposit phosphate. They would find conditions favorable for the latter process only comparatively near the surface, where the excess of carbonic acid might readily escape. Hence the deposits must not be expected to extend to any considerable depth. They are essentially superficial pocket deposits, and in most cases their depth will be limited by the depth of the residual mantle of chert and clay with which they are so intimately associated. It seems probable that the stony variety may extend to greater depths than any of the others, since the process to which it is attributed is one which does not depend directly on surface conditions—the escape of carbonic acid and evaporation of the solution—but upon some conditions, not fully understood, favoring replacement.

The deposits were probably once much more extensive than now. The deepening of the valleys has removed the greater portion of the original deposits, and those which remain are merely the remnants which have accidentally escaped erosion.

UTILIZATION OF THE WHITE PHOSPHATE.

From the foregoing description of the several varieties of white phosphate it will be readily understood that this rock is not available for shipment without undergoing some process of concentration. That a high-grade product can be obtained by the proper concentration is shown from the numerous analyses of selected hand specimens, which sometimes show as much as 80 per cent of lime phosphate. Evidently the method of treatment should differ with the different varieties. The analyses already given show that the stony variety contains less than 50 per cent of lime phosphate, and in it the phosphate is so intimately associated with the silica that no ready means of separating the two elements suggests itself. In case of the other two varieties, however, the problem of concentration is a much simpler one. In case of the breccia, the properties which may be taken advantage of in separating the chert and the phosphate are, first, differences in specific gravity, and, second, differences in hardness. It has been suggested that the two constituents of the rock may be cheaply separated by some form of jigging apparatus. Determinations of their specific gravity, however, do not offer much encouragement for this view. The chert is found to have a specific gravity varying from 2.61 to 2.69. The matrix of lime phosphate with which it is associated has a gravity of 2.83 to 3.07. This difference of 0.3 or 0.4 is probably not sufficient for any simple and cheap device. The specific gravity of the lamellar variety is somewhat higher than that of the structureless breccia matrix.

The difference in hardness between the chert and the matrix suggests the possibility of making a high-grade concentrate, though not of making a complete separation of the two constituents of the rock. As already stated, when long exposed to the atmosphere the matrix becomes considerably indurated, so that it is separated from the chert with great difficulty. Below the surface, however, it seems probable that the phosphate will generally be found soft and granular, so that it can be easily pulverized and separated from the chert. The chert, on the other hand, shows little if any change of hardness from that at the surface. If this softer breccia, therefore, were passed through a suitable crusher, most of the phosphate would be pulverized, while the chert would remain in much larger blocks. If the material thus treated were passed over a screen with a proper mesh, which could be determined only by experiments, it seems altogether probable that a fairly complete separation would be effected. The process suggested above would be a simple and cheap one, and, considering the ease with which the rock can be raised, it seems probable that a cheap and merchantable product could be obtained in this manner.

A part of the lamellar variety would require no further treatment than hand picking at the bank. The quantity of such rock, however, is probably not large, and the greater part of this variety will have to be separated from the clay through which it is found disseminated.

This would probably necessitate, first, screening in the bank, to separate it from the greater part of the clay; second, washing, to remove the remainder of the clay; and, third, hand picking, to remove the free chert with which it is associated. None of these processes are expensive, and if careful prospecting shall show this variety to exist in considerable quantities, it can doubtless be prepared for market at slight expense. It is important, however, for the successful development of these deposits, that thorough prospecting should precede the erection of a plant for treating the rock. The prospecting should be done in a systematic manner and by a competent engineer.

THE UNDERGROUND WATER OF THE ARKANSAS VALLEY IN EASTERN COLORADO.

BY

GROVE KARL GILBERT.

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By G. K. GILBERT.

INTRODUCTION.

Underground water, like stream water, comes originally from the clouds. The rain is divided, after it reaches the ground, into three parts. One part flows away on the surface, making streams; a second part returns to the atmosphere through evaporation, being held by the soil as by a sponge until the air gradually absorbs it; the third part descends through the soil into various formations beneath and constitutes underground water. Some formations are full of small holes, or pores, into which water can enter. In sand, gravel, and some sandstones the pores are large enough to permit water not only to enter, but to flow through. In clay and shale the pores are so minute that water can pass only with extreme slowness. In most quartzites, limestones, and other compact rocks there are practically no pores, and water can pass only where they are broken. Underground water is acted on by gravity, just as stream water is, so that it flows; but its currents are slow, because there is much friction in traversing minute passages. It flows only in the porous, or pervious, formations, and its currents are guided by the impervious formations very much as a stream is guided by its channel. If, then, one knows the character, form, extent, and arrangement of the pervious and impervious formations, he can tell much about the underground currents of water—their sources, their depths, their volumes, their permanence, and even the quality of the water. Thus it is that the fundamental problems connected with underground water are related to the formations beneath the soil; or, in other words, they are geologic problems. There are, indeed, other considerations of great importance in connection with the utilization of such water, considerations depending on the nature of the use proposed, but in each locality the questions relating to natural occurrence are primary.

The writer has been engaged for three summers in the investigation of the geology of parts of the Arkansas Valley, and his attention has been directed chiefly to the determination of the composition, texture, thickness, arrangement, and distribution of the various formations. Not only are these characters the ones on which the distribution of underground water depends, but the subject of underground water has been constantly in view as the leading economic purpose of the investigation. The present paper undertakes to present those results which bear on the more general problems of the utilization of underground water in the district.

For purposes of mapping, the Geological Survey has divided eastern Colorado into rectangular districts, bounded by certain meridians and parallels, and containing each about 950 square miles. The season of 1893 was devoted to detailed and thorough study of one of these rectangular districts, the Pueblo, lying between longitudes 104° 30′ and 105° and latitudes 38° and 38° 30′, the center being a few miles west of the city of Pueblo. In part of this work the writer was aided by Messrs. R. T. Hill and F. H. Newell. During the season of 1894 he had the assistance of Messrs. F. P. Gulliver and G. W. Stose, and the principal field of work was a similar district, the Apishapa, lying between longitudes 104° and 104° 30′ and latitudes 37° 30′ and 38°. The district includes the canyon of the Apishapa River and the lower half of the canyon of the Huerfano. In 1895 no detailed work was done, but a general reconnoissance was made from the head of the main Arkansas Valley, at the city of Canyon, to the eastern boundary of Kansas. The principal line followed was that of the Arkansas River, and the lower slopes of the valley were specially examined, but a number of excursions were also made to the north and south. One northward excursion touched Ordway and Antelope Springs, another Arlington, and a third Cheyenne Wells. Southward excursions reached the Purgatoire River at Bents Canyon, and Two Butte Creek near the butte that gives it its name. If the reader will note the points mentioned on a map of the State, he will readily understand that while the reconnoissance pertains to a belt of some width it by no means covers it, but touches it here and there.

TOPOGRAPHY OF THE DISTRICT.

As the following pages are intended primarily for the residents of the district described, a class whose habits of life tend to give them a broad acquaintance with their geographic surroundings, an extended account of the topography of the valley is not required.

The Great Plains are bounded at the west and the Rocky Mountains at the east by a belt of foothills, which in general runs from north to south. There are, however, many local curves and angles, and one of these affects the Arkansas Valley. Twenty miles south of Colorado Springs the line of foothills turns sharply westward for 20 miles, and then, near Canyon, swings quickly to the south and southeast, holding the latter course for 40 miles (see fig. 45). Within this flexure is a triangular tongue of the plains country, half surrounded by mountain ranges. The Arkansas River, gathering its waters from many a spring and snowdrift in the mountains, passes to the plains at the narrow end of this tongue, traverses its middle, and flows eastward. Its principal affluents outside the mountains are Fountain Creek, rising in high mountains west of Colorado Springs; St. Charles River, draining Greenhorn Mountain and neighboring uplands; Huerfano River, draining Huerfano Park, a more southerly embayment of the Rocky Mountain front; Apishapa River, flowing from Spanish Peaks; and Purgatoire River, rising on the eastern slope of the Culebra Range. Of these mountain-born streams, the Fountain alone traverses the northern slope of the Arkansas Valley and holds a southerly course; the others flow on parallel lines toward the northeast. All tributaries east of the Fountain and the Purgatoire head within the plains.

For half of its course between Canyon and Pueblo the Arkansas is closely hemmed in by rock bluffs 200 feet high, with cliffs of limestone at top. Elsewhere its immediate valley is more open, usually with a

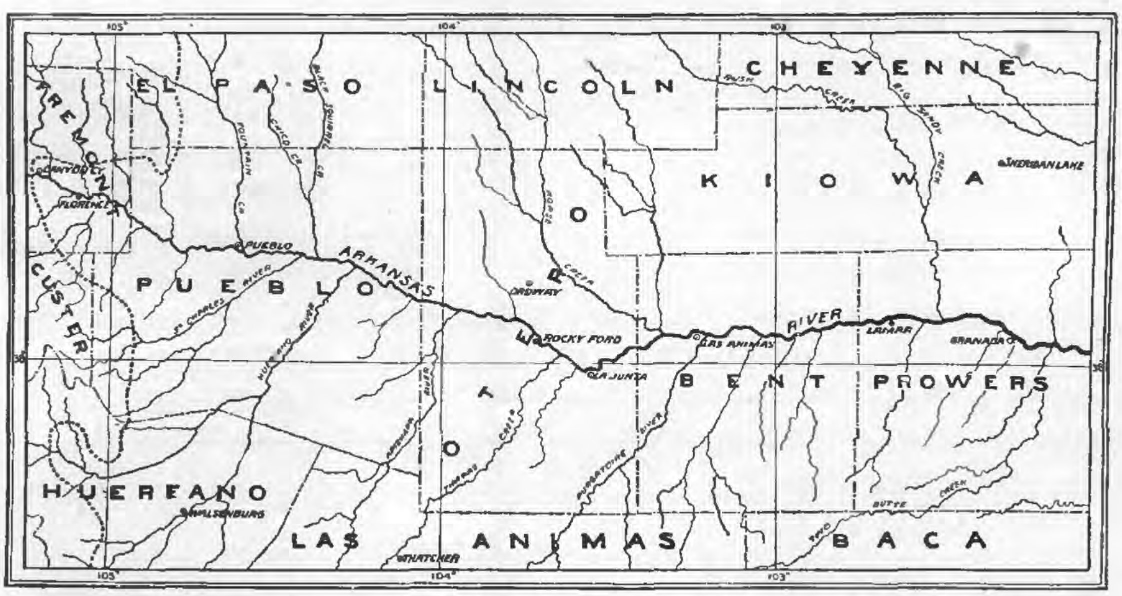

FIG. 45.—Map of part of Colorado, including the district to which this report pertains.

sharp ascent on one side to a gravelly mesa, and a long, gradual slope on the other. Farther back the ascent is broken by terraces of gravel or sand or by tracts of clayey bad lands, and here and there by rocky cliffs and mesas. East of the Fountain the northern slope is characterized chiefly by broad, gently undulating plains, illustrating the typical character of the Great Plains region. On the southern slope similar plains occur east of the Purgatoire, but the topography is in general more accented. The Purgatoire runs for 50 miles in a canyon between sandstone walls, and the Apishapa and Huerfano have shorter canyons of the same character.

At the city of Canyon the altitude of the river is 5,325 feet; at the Kansas line, 3,350 feet, the total fall being 1,975 feet. The distance by rail is 189 miles, but by river it is 218 miles, giving an average grade of 9 feet per mile. Considering the stream in three sections, the fall from Canyon to Pueblo is 15 feet per mile, from Pueblo to La Junta 8 feet, from La Junta to the Kansas line 7.3 feet. In ascending northward or southward from the main stream the rise is more rapid. On the lines of main tributaries it averages about 25 feet per mile for the first 50 miles, and the general rise of the intervening slopes is 30 feet per mile.

GEOLOGY OF THE DISTRICT.

The principal rocks are shales, sandstones, and limestones, which alternate with one another in a series of layers. Each layer or formation is very broad, extending for scores or hundreds of miles, but is of comparatively small thickness. One rests on another like the leaves of a book. Each formation was originally a soft sediment at the bottom of a sea or ocean. The shale was mud; the sandstone was sand; the limestone was limy ooze. These sediments were brought to the ocean from neighboring lands by rivers, and were spread over the ocean bottom by ocean currents. The extent of the ocean was changed from time to time, and changes occurred in the character of the rivers; and in consequence of these changes the character of sediment was not always the same. Mud, limy ooze, and sand were deposited in alternation, building up a varied series of layers. Afterward, by pressure or by chemical changes, the sediments were hardened into rocks such as are now found.

The character of the lower members of this series of formations is not well known, and with reference to the problem of water supply is of little importance. It will be necessary here to speak only of the Juratrias and the Cretaceous rocks. The Juratrias are the older, and underlie the Cretaceous.

JURATRIAS ROCKS.

These consist chiefly of sandstone, conglomerate, and shale, but include also beds of limestone and gypsum. The number, character, and thickness of the formations vary greatly from place to place. In the foothills near Beulah the series includes a rapid alternation of sandstone, conglomerate, and shale, all characterized by a deep-red color, and the total thickness is there about 2,000 feet. At the northeast, where Turkey Creek crosses the foothills, this series is thinner and has less conglomerate, but retains the red color. Above it are shales of various brilliant hues—orange, white, blue, green, and chocolate—mostly with a considerable admixture of sand. Interspersed among them are several layers of yellowish sandstone, and also several beds of gypsum, either white or mottled with gray. The entire thickness of this upper series is over 500 feet. On the Purgatoire, above Bents Canyon, the most prominent member is a brilliant-red sandstone, about 150 feet thick, beneath which are softer beds of the same color and of greater thickness. Above it are pale-greenish shales, inter.

A CHARACTERISTIC EXPOSURE OF THE GREENHORN FORMATION NEAR THATCHER, COLORADO.
From photograph by F. P. Gulliver.

bedded with white and gray gypsum, white limestone, and, toward the top, with orange sandstone, the whole having a thickness of 220 feet. On Two Butte Creek, near Two Buttes, the most conspicuous bed is again a red sandstone, 150 feet thick. Below this are 150 feet of red shales, and these rest upon sandstones and shales of various dark hues. Above the red sandstone are 50 feet of red shale, and then occur gray sandstones and gray sandy shales in alternation for several hundred feet, the upper limit not having been determined.

In a general way, the Juratrias rocks of this region are characterized by considerable thicknesses of red strata, and as beds of that color seldom appear in the overlying formation they may be used for the identification of the Juratrias series wherever it is penetrated by the well-borer's drill.

Except in the immediate vicinity of the mountains, the sandstones of the series are of such fine texture as to prevent the circulation of water, and the shale, limestone, and gypsum beds are impervious. No successful wells have obtained their water from these rocks; and as there are no rocks beneath them which have yielded fresh water, any well borer of the Arkansas Valley who has penetrated 50 feet of red rocks may safely conclude that deeper exploration will prove unprofitable.

CRETACEOUS ROCKS.

Above the Juratrias beds is a great system of formations called Cretaceous. There is reason to believe that in several portions of the Arkansas Valley the deposition of sediment was interrupted after the Juratrias and before the Cretaceous. In those places the sea bottom was uplifted so as to constitute land, and the Juratrias sands and clays were partly washed away by rains and rivers before the ocean returned and other deposits were made. During the earlier stages of Cretaceous deposition there were also variations in the geography of land and sea, the coast line shifting to and fro; but this period was comparatively brief, and afterward the ocean held uninterrupted sway for an immense period, during which several thousand feet of deposits were accumulated.

The deposits have been classified in five subdivisions or groups, as given below. The name of the highest is placed uppermost, and the others in order, just as they overlie one another in nature; but they are numbered from below upward, so that the numbers represent their order in point of time, the lowest having been first made and the highest last.

5. Fox Hills group.
4. Pierre group.
3. Niobrara group.
2. Benton group.
1. Dakota group.

DAKOTA GROUP.

The Dakota group contains so much sandstone that it is frequently called "the Dakota sandstone," and in this respect it is strongly contrasted with the other Cretaceous groups, which in this district consist chiefly of shale. It also differs from the other members of the system in that it exhibits considerable variability from place to place, while the others are more nearly uniform in all parts of the district.

The Dakota sandstones are prevailingly of a yellowish-gray color. Some of the lower members, especially in the region of the foothills, are nearly white, and some of the upper members at the extreme east are of a dark-gray color, changing to a deep brown, almost black, on weathered surfaces. At the east the surface colors of lower beds include brilliant tints, especially orange, but the colors of fractured surfaces are usually dull and rather pale. There are also notable variations in texture. The upper layers are usually close textured; that is, the original pores between the sand grains are well filled with cement, so that the rock is but slightly porous and does not permit a free circulation of water. The lower beds are more open in texture, and are in general somewhat coarser, especially in the region of the foothills. Their open texture is due to the fact that but little cementing material has been introduced. The rock is feebly coherent, so that when it is encountered in boring it is readily reduced to sand by the blows of the drill, and is ordinarily described by the drillers as sand rather than as sandstone. In the region of the foothills the lower sandstones often contain many small pebbles, so as to approach conglomerates in character. In many of the beds the iron compounds which constitute their coloring matter seem to be disseminated in particles, giving to the fractured surface a speckled appearance.

Between the sandstones are shales, usually light or dark gray and somewhat arenaceous. They contain many shreds of vegetable tissue changed to coal, and at certain horizons this carbonaceous matter is so abundant as to render them nearly black. Some of the shales are also locally of a greenish-brown color. In the neighborhood of the mountains fully four-fifths of the group is of sandstone, and the only important shale bed is near the top of the series. In the eastern part of the district thick shale beds alternate with sandstones throughout the group, and their total thickness is probably greater than that of the sandstones. In all localities the uppermost sandstone beds are thin and alternate with gray shales, similar to those of the Benton group lying next above. Some of the shales in this transition zone have been found to have the qualities of fire clay.

The sandstones of the Dakota group are the chief water-bearing rocks of the district, and all artesian flows are obtained from them. They are therefore of peculiar importance in the present connection,

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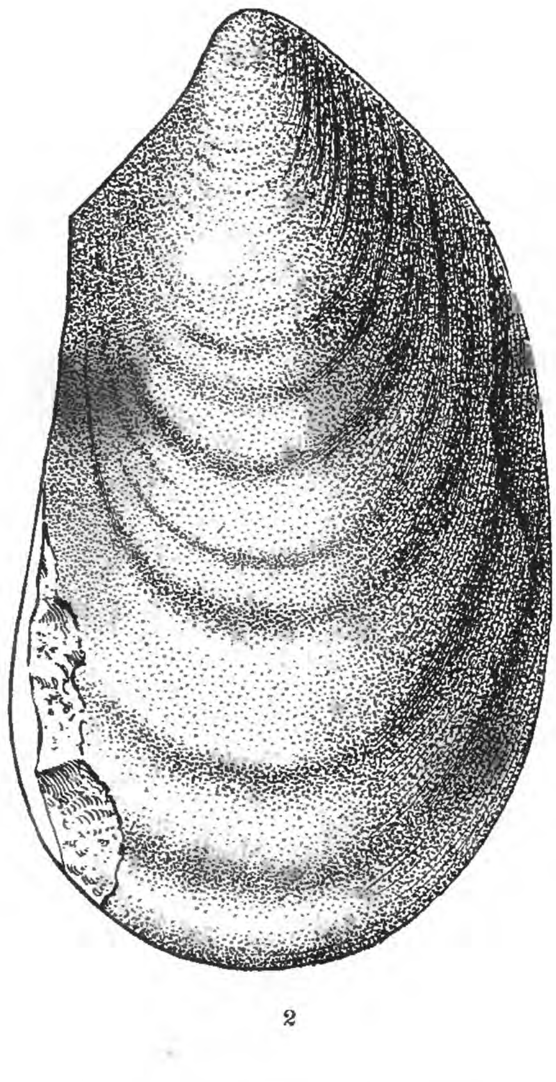


2

INOCERAMUS LABIATUS, A FOSSIL BIVALVE SHELL OCCURRING IN ABUNDANCE IN SOME LAYERS OF THE GREENHORN FORMATION.

Fig. 1. A small individual, in which the concentric ridges of the shell are unusually strong.
Fig. 2. An individual of moderate size.

and it will be advantageous to give attention to the circumstances under which they were deposited.

The material of all sediments which gather at the bottom of seas is derived from the waste of adjacent land surfaces, and is transported from the one region to the other by currents of water, chiefly the water of streams. Where rivers enter the sea their currents are gradually checked, and there is a sorting of the transported particles. The coarser particles fall to the bottom first; the finer are carried farther. Thus the sand grains accumulate near the shore and the mud particles at a distance from shore. Waves also coöperate in sorting and distributing. To a certain extent they attack the shore, and, loosening its material wash it away. They also drift the particles brought by rivers one way and another along coasts, building sand and sometimes gravel into beaches. The finer particles are by the same agitation sorted from the coarser, and they eventually come to rest in deeper water. The sand zone constituting and bordering the beach is a narrow belt as compared to the broad bottom which receives the fine sediments, and sandstones, resulting usually from the consolidation of beach sands, would be formations of small extent but for the fact that coasts migrate. The changes in the height of land, which through all geologic time have modified the geography of the earth, incidentally cause coasts to advance over and retreat from the slopes of the land, and the zone of sand accumulation is thus carried gradually to and fro, so that the resulting sand formation may in the course of time become as broad as the formations of mud and limy ooze.

We do not know the positions of the coast during the various stages of the Dakota sea, but the alternation of sandstones and shales seems to indicate that it was shifted to and fro over the same district a number of times. Its movements were probably irregular, and the mouths of sand-bearing rivers were not always in the same places, so that the distribution of sand within the formation is uneven. At any rate, great variety is found in the details of rock succession within the group. Where the formations now appear at the surface and are examined and measured, it is found that no two localities give precisely the same sequence. The textures of the beds are comparatively uniform, but their thicknesses vary rapidly from place to place, so that a measurement at one locality will not warrant prediction as to the precise thicknesses to be found at another locality a few miles away. The same differences appear when the records of well borings are compared.

The character of the group can therefore be given only in general terms. It consists of an alternation of sandstones and shales, the sandstones having much the greater thickness at the west and the shales somewhat the greater thickness at the east. The total thickness is greatest near the mountains, where it averages about 300 feet, and has a maximum near Beulah of over 500 feet. In the eastern part of the district it ranges from 200 to 250 feet.

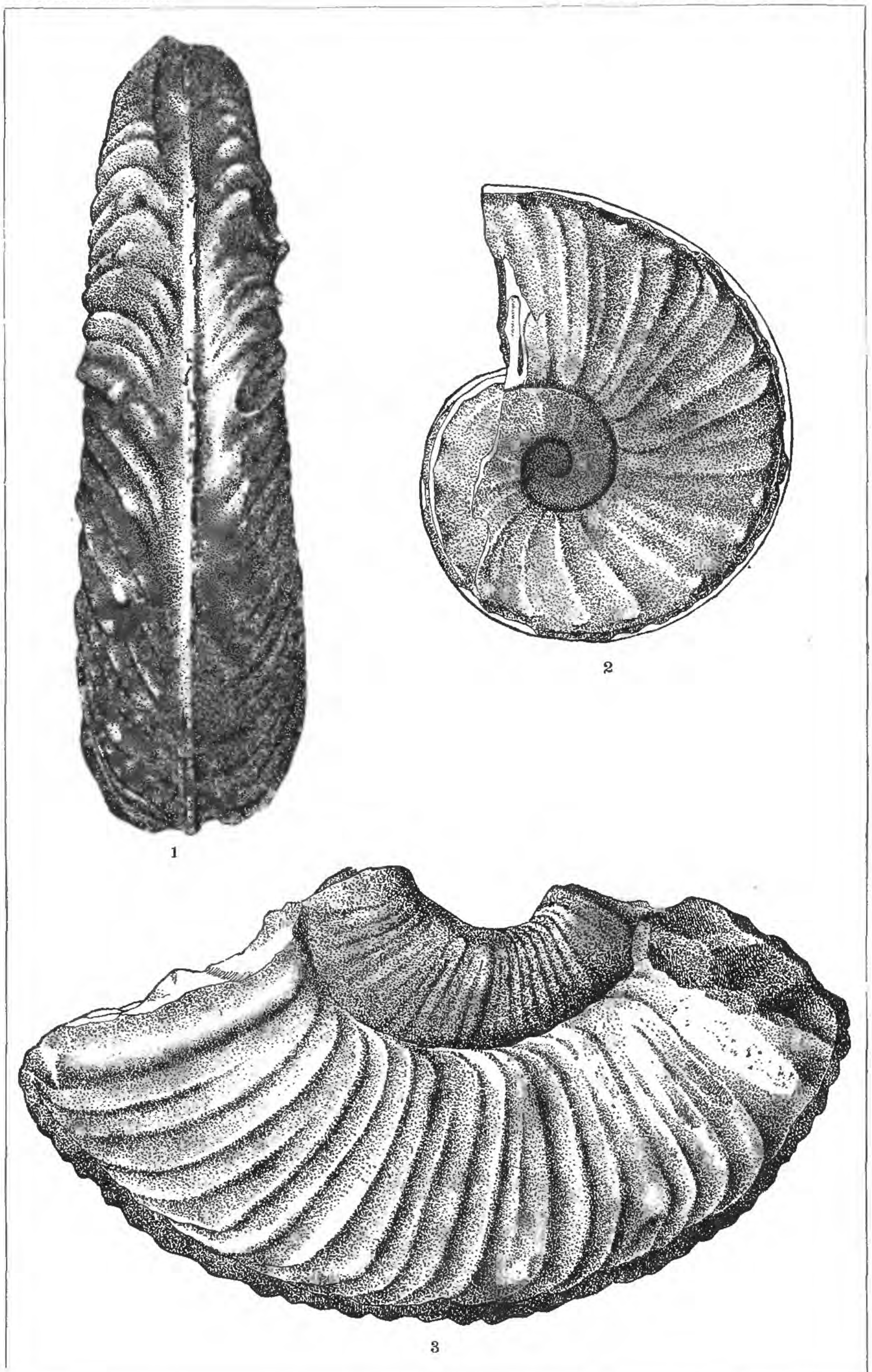
BENTON GROUP.

The members of this group are so regular within the limits of the district that many of them are everywhere recognized, and it has been found advantageous to consider the group as consisting of three distinct formations. These are:

3. Carlile shale.
2. Greenhorn limestone.
1. Graneros shale.

Graneros formation.—The Graneros shale rests directly on the uppermost sandstone of the Dakota group. Its thickness is from 200 to 210 feet. It is characteristically a laminated, argillaceous, or clayey shale with very little admixture of limy or sandy material. Where the shale has not been acted on by the weather it shows little tendency to split, and its lamination appears chiefly as a delicate marking of the surface. Brief exposure to the weather causes it to divide into thin flakes (laminæ), and prolonged weathering reduces it to clay. The middle third of the formation is dark gray, and thin bands of it are nearly black, as though highly bituminous. The upper and lower parts are medium gray. At various horizons, especially in the lower part, are thin beds of a white, structureless clay, resembling in appearance the fire clays which underlie coal seams, but a test shows that they have not the refractory property of fire clays. At various levels and localities are rows of calcareous concretions, and one of these rows, from 20 to 30 feet above the base of the formation, changes in certain districts into a layer of dark-gray limestone, with a maximum thickness of about a foot, which acquires by weathering a surface of bright orange. There are also, especially in the eastern part of the district, a few thin calcareous layers containing many fossil shells of small oysters. Twenty or thirty feet below the top of the formation is a rather persistent sandy limestone, only 1 to 3 inches thick, and this also contains fossils. In the eastern part of the district one or two other beds similar to this are found above it. These various exceptional layers have collectively a thickness of only 4 or 5 feet, so that, though very useful to the geologist in mapping the formation, they qualify but slightly its typical character as argillaceous shale.

Greenhorn formation.—This formation is 25 to 40 feet thick. It consists of strata of limestone, from 3 to 12 inches thick, separated by somewhat thicker shale beds. (See Pl. LVI.) The limestone is pale bluish-gray, fine grained and compact. Where exposed to the weather most of the beds are divided by vertical approximately parallel seams into plates from one-fourth of an inch to 1 or 2 inches in thickness. Of the thicker beds there is only one, near the bottom of the series, which does not exhibit this vertical structure. The shales have a light-gray color, are laminated, and contain more lime than do those of the



PRIONOCYCLUS WYOMINGENSIS, A FOSSIL SHELL FOUND AT MANY LOCALITIES IN THE DARK LIMESTONE AT TOP OF THE CARLILE SHALE AND JUST BENEATH THE WHITE TIMPAS LIMESTONE. THE SHELL IS COILED, SOMEWHAT LIKE THAT OF A LAND SNAIL.

Fig 1. An edge view.
Fig. 2. A side view of a small individual.
Fig. 3. A side view of a fragment showing parts of two whorls of the coil.

NODULES OF MARCASITE. Natural size.

These are characteristic of the lower part of the Timpas limestone.

formations above and below. Among them are a few bands of white clay, like that mentioned as occurring in the Graneros shale.

Several of the limestone beds contain fossil shells in abundance, chiefly an oval bivalve, *Inoceramus labiatus*. Fossils are found also in other formations, but the assemblage of shells is different at different levels. This particular shell, although not entirely absent from some other formations, is abundant only in certain of the Greenhorn beds, and it thus serves as a sort of earmark by which those beds can be recognized and discriminated from certain other limestones for which they may be mistaken. A picture of *Inoceramus labiatus* is therefore introduced in Pl. LVII, in the hope that it may aid residents of the district in determining the geologic formations which occur at the localities in which they are interested. As will be explained later, the geologic formation found at the surface is an index of the depth to which it is necessary to drill in order to reach artesian water.

Carlile shale.—This shale is from 175 to 200 feet thick, and in its more general features resembles the Graneros. Its dominant color is medium-gray, and the middle third is darker. In the eastern part of the district its whole body is finely laminated and argillaceous. Farther west the upper fourth contains some sand, and its lamination becomes coarser or disappears. Portions of it, especially near the top, locally assume the character of sandstone, taking a light-yellow color. In the so-called Sand Hill, west of Pueblo and south of Rock Canyon, some layers of the sandstone are quarried for flagging and foundation rocks, and it is suitable for such use in a considerable district west and south of that place. While this rock is somewhat friable, it is not of open texture; the pores between sand grains are occupied by argillaceous material, so that it does not constitute either a reservoir or a conduit for underground water. Farther east the sandstone is often replaced by a purplish limestone, 2 or 3 feet thick, in which a large coiled shell, *Prionocyclus wyomingensis* (Pl. LVIII), is somewhat abundant, though so poorly preserved as usually to be seen only in outline.

Between 20 and 50 feet from the top of the formation are many calcareous nodules or concretions, ranging from a few inches to 4 or 5 feet in diameter. In form they are thick-ovoid to spherical. The outer layers have what is called the cone-in-cone structure, seeming to be made up of a system of interlocking cones with apices all pointing toward the middle of the concretion. The inner parts are of even, fine texture, and gray color. In all the larger specimens the interior is traversed by gaping cracks, which are partly or wholly filled by crystalline calcite. The first-formed calcite, lying adjacent to the walls of the cracks, is usually of dark tints, chiefly wine color; but the last-formed is white or transparent, and is often developed in large crystals of great beauty.

From 50 to 75 feet above the base of the formation there is sometimes found, especially in the eastern part of the district, a thin, limy bed with fossils.

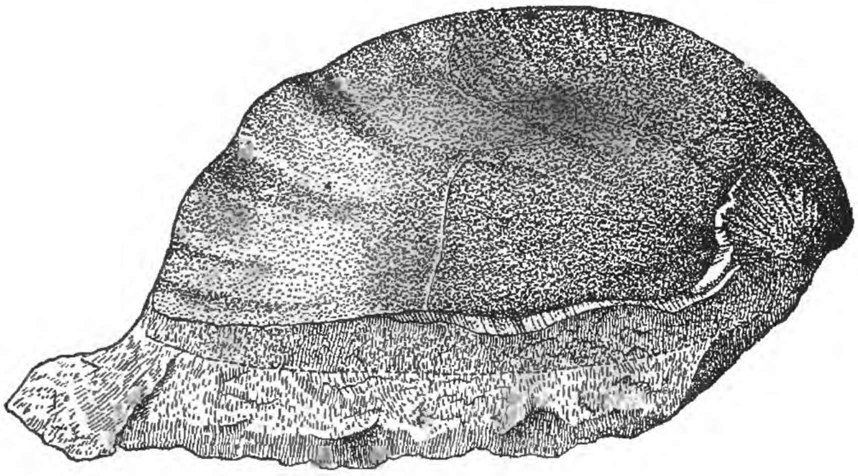
The group as a whole.—Briefly summarizing the characters of these three formations, one may say that the Benton group has a total thickness of 400 to 450 feet. It is a body of gray shale, divided midway by a limestone formation, and including at top a thin, purplish limestone or a thicker yellow sandstone. Its thickness at all points of measurement is so nearly the same that great dependence can be placed upon it in estimating at various localities the distance which must be traversed by the drill to reach the water-bearing Dakota sandstones below.

NIOBRARA GROUP.

The formations of this group are chiefly of shale, but the members of it which are most frequently exposed to view, and thus attract attention, are limestones. Its entire thickness has been measured at a few points only, being there found to be about 700 feet, but rough approximations in other localities give the impression that its thickness is nearly uniform.

Timpas formation.—The lower members of the Niobrara group are collectively called the Timpas formation. The general thickness of the Timpas is 175 feet, and it may be characterized as a series of limestones and calcareous shales with prevailing pale colors.

At base is a limestone series about 50 feet thick. The individual beds range in thickness from a few inches to 3 feet, the average being about 1 foot. They are separated by layers of gray shale, usually 1 or 2 inches thick. The limestone has a light gray color, which becomes creamy white on weathered surfaces. It is compact and rather fine grained, and where exposed to the weather breaks up into rough flakes, of which the longer dimensions are parallel to the bedding. This peculiarity ordinarily serves to distinguish it from the Greenhorn limestone, which cleaves into vertical plates. Near the eastern edge of the district its texture is somewhat coarser, its color is paler, and the fractured surface resembles chalk. Still farther east, especially in Iowa, the rock acquires all the characters of a true chalk. In its lower layers are small nodules of iron sulphide, which are converted by the chemical reaction of the air to limonite. As the limestone is broken up and removed by the action of the weather, the more resistant nodules are freed from their matrix so as to lie loose on the surface. They are of a dark-brown color and of oval or cylindrical form, with a diameter of about half an inch. Their surfaces are not even, but are set with angular projections, the ends of crystals (Pl. LIX). The characteristic fossil of the limestone is a thick bivalve shell (*Inoceramus deformis*), the outer surface of which is usually covered by the shells of a small oyster (*Ostrea congesta*). The shell itself can rarely be found free from its matrix, but a limestone cast having the form of its interior is frequently seen, and can always be discovered by a little search where



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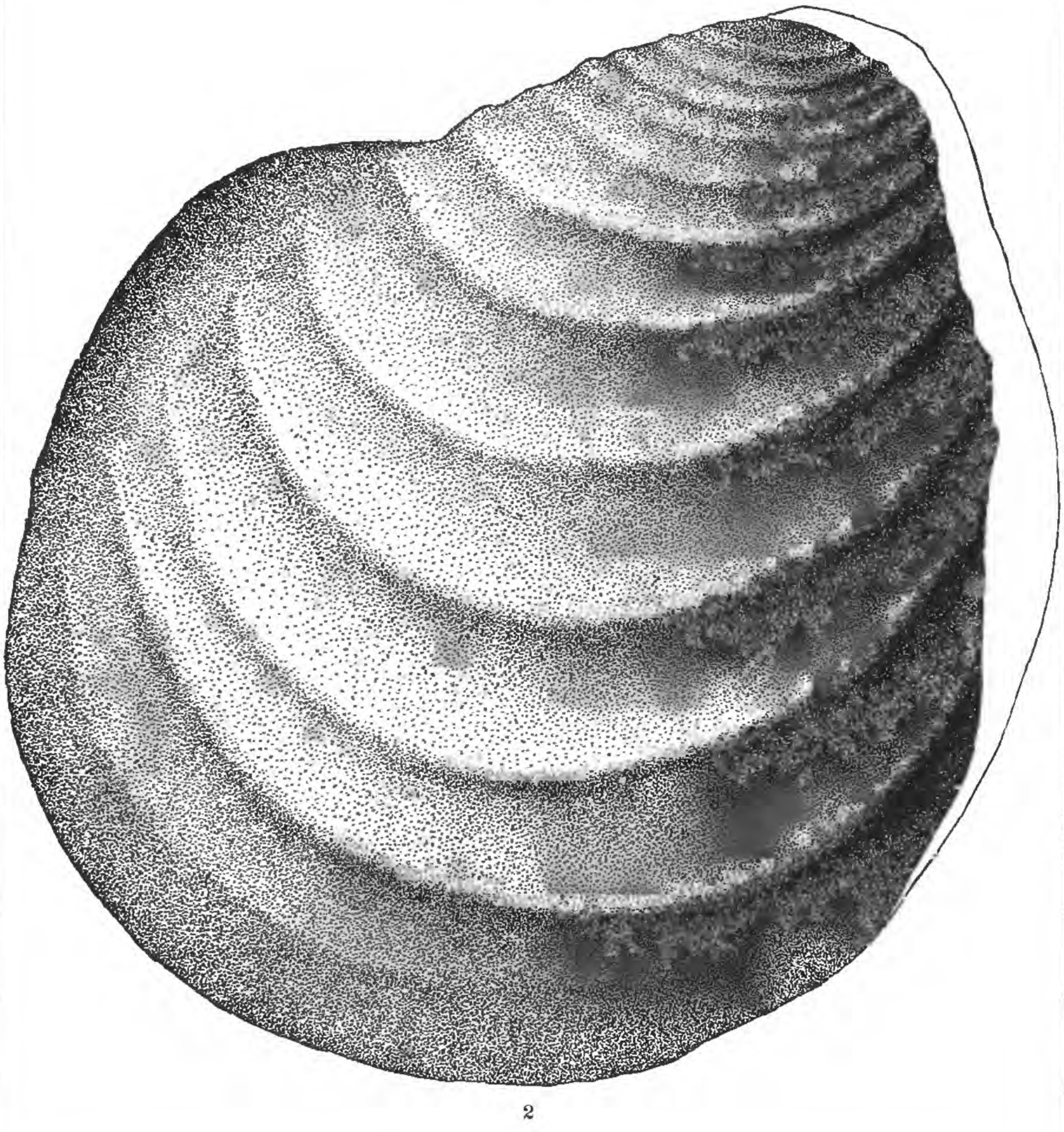

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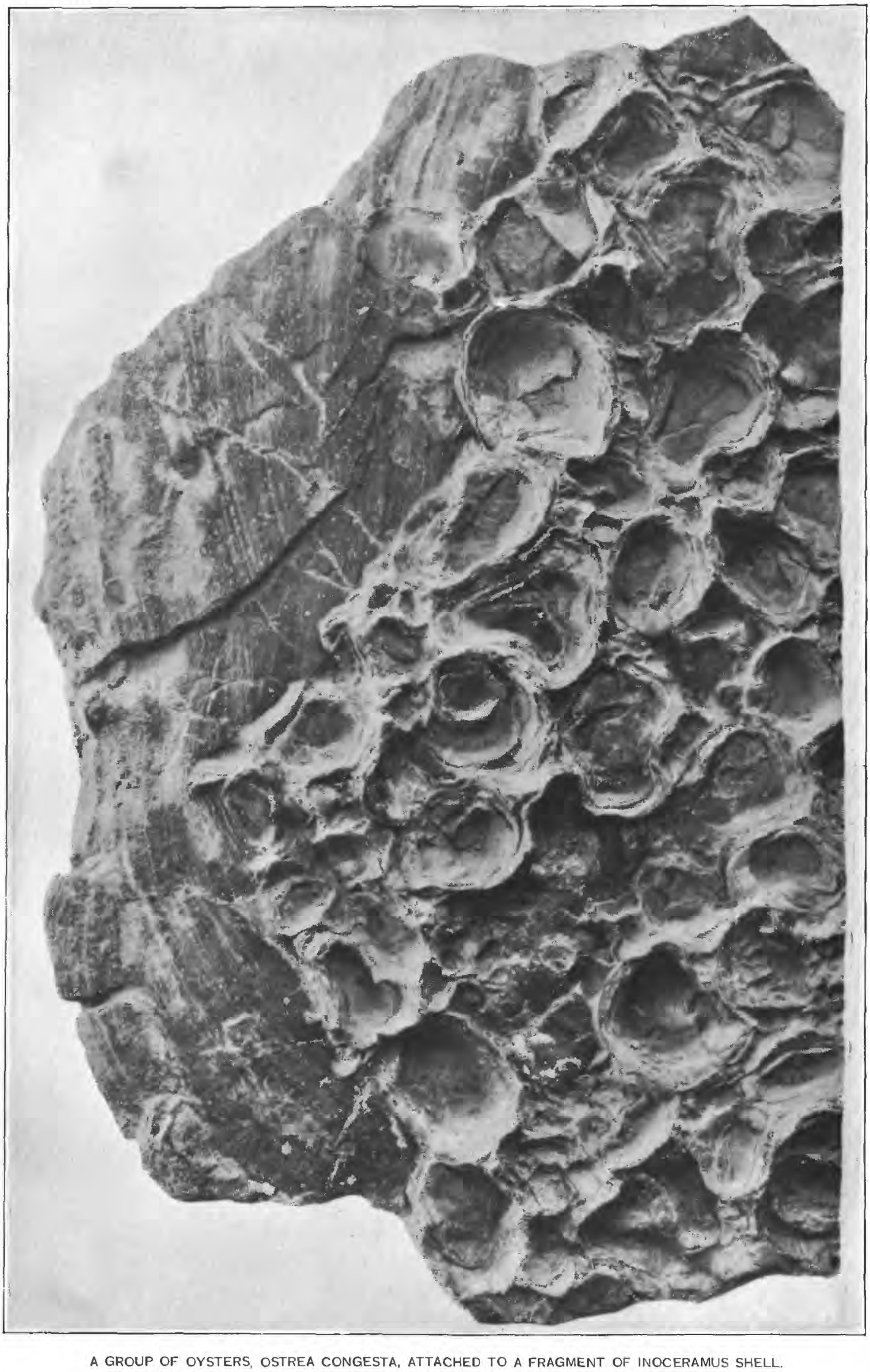
INOCERAMUS DEFORMIS, A FOSSIL BIVALVE SHELL FOUND AT MANY LOCALITIES IN THE TIMPAS LIMESTONE. THE TWO VALVES ARE USUALLY SEPARATED.

Fig. 1. The edge of a small individual.
Fig. 2. The side of an individual of moderate size.

The mud which once filled the shell was hardened into stone and the shell was afterwards broken away, so that the illustration represents casts of the interiors of the shells. In Fig. 1 a small portion of the shell remains.



A GROUP OF OYSTERS, OSTREA CONGESTA, ATTACHED TO A FRAGMENT OF INOCERAMUS SHELL.

Such groups are found in several formations, but they are peculiarly abundant in the upper part of the Timpas formation.

the rock is quarried or is worn by a stream. Its form is suggestive of the hoof of a horse (Pl. LX).

The upper limit of the limestone is indefinite. It passes gradually into a light-gray, limy shale, which contains occasional thin beds of limestone and has a total thickness of 100 or 125 feet, terminating at top in one or two layers of chalky limestone containing several species of fossil shells and also the remains of fishes. The most abundant shell is a very broad, flat bivalve belonging to the genus Inoceramus, and usually covered by *Ostrea congesta*. The shell of Inoceramus has a fibrous structure at right angles to the surface, causing it to break easily, and the individuals of this species are always broken into many pieces, so that the specimens actually found are fragments of plate-like shells with oysters attached to one side (Pl. LXI).

Apishapa formation.—The upper part of the Niobrara group constitutes the Apishapa formation. It is chiefly an argillaceous, laminated shale, of dark-gray color, but it is modified by atmospheric action to a considerable depth, acquiring a yellowish color and rougher texture. Gypsum in thin plates is somewhat abundant, and in unweathered specimens a short search will always discover oval fish scales from one-third of an inch to an inch in diameter. At top a few layers contain so much lime as to constitute an impure limestone, and they have been quarried at some points, especially at Pueblo, for foundation stones, etc. They contain fish scales and a few fish bones. At various horizons, especially in the eastern part of the district, are calcareous concretions, usually of considerable size. They are never spherical, like those of the Carlile formation, but are broadly ellipsoidal, and at a few points they coalesce with one another so as to form a continuous bed several rods in extent. Below the middle of the formation a series of these concretions have internal cracks similar to those of the concretions found in the Carlile formation, but containing, in addition to calcite, large crystals of barite, or heavy spar, a translucent mineral with faint-bluish color, which may be distinguished from calcite by its greater weight. At points south and west of Fowler barite has been collected by mineralogists for exhibition in museums. The entire thickness of the formation is approximately 500 feet.

PIERRE GROUP.

Above the Niobrara group is a great deposit of laminated, argillaceous shales, not interrupted by sandstone, limestone, or other hard layers. In the vicinity of Florence, where the whole of the group is seen, its thickness has been estimated as more than 4,000 feet.[1] In other parts of the district only the lower part of the group occurs, and it is probable that the thickness does not exceed 2,500 feet. There are considerable variations in color, texture, and contents, from bottom to top of

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[1] The Florence oil field, Colorado, by George H. Eldridge: Trans. Am. Inst. Min. Eng., Vol. XX, 1891, pp. 442-462.

the series, and by their aid several zones have been recognized, but none of these are sharply limited, and it has not been practicable to distinguish definite formations.

The lower part, for a depth of 400 or 500 feet, is of medium-gray color and has a certain roughness of texture due to minute flakes of selenite, the crystalline form of gypsum. It is practically barren of fossils, for, though their presence can be detected by careful search, they are rarely so well preserved that they can be collected. It contains so few concretions that their scarcity serves to distinguish it from the next zone, where they are abundant.

Above the barren zone is a zone of similar color, but with less selenite, characterized by a great abundance of ovoid concretions, ordinarily from 4 to 8 inches thick and two or three times as broad. These are dark gray on surfaces of fresh fracture, fine textured, and tough. They consist of carbonate of lime and carbonate of iron. At certain horizons they contain fossils, but these are not a conspicuous feature. Under the action of the weather they break up into angular fragments a fraction of an inch in diameter, which have the color of iron rust; and on bare slopes these fragments occupy so much of the surface as to give it a reddish-brown color. The thickness is approximately 600 feet.

Beginning in the lower, or Rusty, zone, and extending upward for 100 or 200 feet, where the shale becomes paler, is a zone characterized by the abundance of a peculiar fossil, *Baculites compressus*. This is a relative of the nautilus, but its shell, instead of being coiled like those of the nautilus and snail, is straight. It has the form of a flattened cylinder, tapering slightly from one end toward the other. Many of the fossils are of dull-gray color and stony texture, but others are white or pearl-gray and retain the pearly luster of the living shells. They are not confined to this horizon, but are more abundant here than above or below. The largest individuals occur somewhat higher, and it is one of these that is pictured in Pl. LXII.

The Tepee zone, though grading insensibly into the zones above and below, has characteristics which are somewhat striking. Its thickness is estimated at 1,000 feet. The shale is of fine texture and medium-gray color. Concretions are rather abundant, and larger, on the average, than in the Rusty zone. They ordinarily range in thickness from 6 to 12 inches and are several feet in horizontal extent. As in the other zones, they occur along certain lines or levels instead of being scattered irregularly through the shale. In them are preserved fossils of great beauty and often of considerable size. Among these are a large baculite, frequently 2 or 3 inches in diameter (Pl. LXII), and several coiled shells related to the ammonite (Pls. LXIII, LXIV, and LXV). A large, smooth bivalve, *Inoceramus sagensis*, ranges from 4 or 5 inches to a foot in diameter (Pl. LXVI, fig. 2). All these shells, when freshly broken from the concretions, are white and retain the pearly luster; but where acted on by the weather they have either the dull gray of the concretions or the yellow of iron rust.

BACULITES COMPRESSUS. SIDE VIEW OF A LARGE INDIVIDUAL.

The oval diagram shows the form of the cross section. Individuals of this size are found in the Tepee zone of the Pierre shale. Smaller individuals are more abundant in the Baculite zone.

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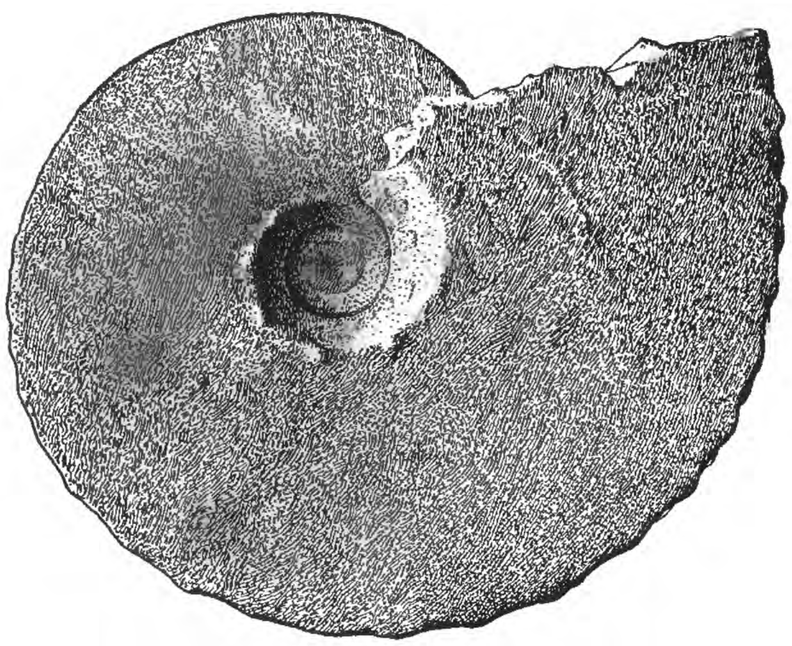

1

PLACENTICERAS PLACENTA AND SCAPHITES NODOSUS.

These fossil shells are found at many localities in the Tepee zone of the Pierre shale, and ***Scaphites nodosus*** occurs also in the limestone cores of the Tepee Buttes.

Figs. 1 and 2 give side and edge views of a small Placenticeras. Specimens often have a diameter several times as great.

Fig. 3. A small variety of ***Scaphites nodosus.***

The zone is further characterized by what have been called "Tepee cores." These are masses of coarse-textured, gray, fossiliferous limestone, irregular or rudely cylindrical in form, and standing vertical within the shale mass. Ordinarily they are from 5 to 30 feet in horizontal diameter, and their vertical extent is greater. As the wash of rains carries away the shale, these cores, being more resistant, are left projecting from the surface, but they do not stand as columns. Fragments broken from the top by frost fall on the adjacent shale and protect part of it from the rain, so that the position of each core is marked by a conical hill of shale, with the limestone projecting slightly at top. These little hills (Pl. LXVII) have been called "Tepee buttes," on account of their resemblance to the tepees or lodges of the Shoshone and other Indians. The fossils in the limestone are of great variety, including all kinds that occur in the surrounding concretions, but the most abundant species is a bivalve shell, about an inch in width *Lucina occidentalis* (Pl. LXVI, fig. 1). It is possible that these cores do not everywhere characterize the shale at this horizon, but they have been found at various points from Canyon to Cow Spring.

Above the Tepee zone the shales are comparatively, though not absolutely, barren of fossils. Their color is in general darker; selenite is somewhat abundant; concretions are less abundant, and at a number of horizons are thin, discontinuous, limy layers with cone-in-cone structure. There are also fillets of structureless white clay similar to that occurring in the Carlile formation.

Measured from the base of the group the middle of the Rusty zone has a height of about 800 feet, the middle of the Baculite zone 1,200 feet, and the middle of the Tepee zone 1,700 feet.

FOX HILLS GROUP.

The Fox Hills group is composed chiefly of sandy shale, which grades downward into the argillaceous shale of the underlying Pierre and upward into a yellow sandstone. Within the district it occurs only in a small tract near Florence, where its thickness is reported by Eldridge as 450 feet. Lying 5,000 feet above the water-bearing Dakota sandstones, it is not traversed by artesian wells, and its characters need not be further described in this place.[1]

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[1] For the benefit of the reader who may have occasion to consult other works treating of the geology of the Great Plains, it is proper to state that the groups here enumerated do not comprise the whole of the Cretaceous system of the plains, and also that various other designations are in use for some of the strata here included. The first classification of the Cretaceous of the plains was by F. B. Meek and F. V. Hayden, who gave the names:

5. Fox Hills.
4. Fort Pierre.
3. Niobrara.
2. Fort Benton.
1. Dakota.

The Laramie formation, which in some regions overlies the Fox Hills, is now classed with the Cretaceous, and the Comanche series, which has great development in Texas, has been recognized as of Cretaceous age and older than the Dakota. It is possible that some of the beds here classed as Juratrias may eventually be correlated with the Comanche. In the reports of the Fortieth Parallel Survey,

RÉSUMÉ OF THE CRETACEOUS FORMATIONS.

In their more general features the Cretaceous formations constitute a simple system. At base are a few hundred feet of sandstones with interbedded shales; above are several thousand feet of shale, varied somewhat in texture and color, interrupted here and there by beds of limestone, and characterized at various horizons by peculiar fossils and peculiar concretions. These general facts are represented in fig. 46, which is drawn to scale so as to show the relative thicknesses of the principal component beds. The undulating lines of the Dakota group indicate the varying thickness and distribution of the Dakota sandstones. The straight lines above represent the comparative uniformity of all the other formations. The tepee cores are shown by vertical lines. One margin of the diagram is shaped to indicate relations of hardness, the harder beds being made to project beyond the softer, as they sometimes do on the face of a cliff. The Fox Hills group and the upper part of the Pierre are omitted as unimportant with reference to problems of water supply.

While it is probable that all these formations once extended over the whole district, the present condition is very different. They have been worn away unevenly, so that over certain areas the Pierre shales are shown at the surface, over other areas the Niobrara formations, over others the Benton, and over others the Dakota. Wherever any of the higher formations occupies the surface there is reason to believe that the Dakota lies beneath and can be reached by boring. Moreover, the general facts in regard to thickness enable anyone who has determined which formation constitutes the surface at any point to predict, with fair approximation, the depth to which it would be necessary to drill in order to reach the water-bearing strata of the Dakota. When the detailed work of the United States Geological Survey has been completed in the district its maps will record such information with considerable precision; but the inquirer need not wait for that final work if

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the Fort Benton, Niobrara, and Pierre are classed together under the name Colorado Group. C. A. White, in 1878, classed together the Fort Benton and Niobrara under the name Colorado, and the Fort Pierre and Fox Hills under the name Fox Hills. This usage was followed by various writers. In 1889 Mr. George H. Eldridge proposed "Montana" as a generic term including the Fort Pierre and Fox Hills, retaining "Colorado" as a generic term for Fort Benton and Niobrara. For the purposes of the present paper the more inclusive terms have not been required, but, on the contrary, it has seemed desirable to subdivide the Benton, Niobrara, and Pierre groups.

The names applied by the writer to formations and zones within those groups are here published for the first time. The Graneros shale is so named from a creek in longitude 104° 47′, latitude 37° 57′, where the formation is well exhibited. The title was suggested by Mr. R. C. Hills. The Greenhorn limestone takes its name from Greenhorn station, 14 miles south of Pueblo, and from Greenhorn Creek. The Carlile shale is named from Carlile Spring and Carlile station, 21 miles west of Pueblo. The Timpas formation is named from Timpas Creek, which enters the Arkansas below Rocky Ford. The Apishapa formation is named from Apishapa River, which reaches the Arkansas near Fowler.

In a report on the fossils of the Colorado Group (Bull. U. S. Geol. Survey No. 106), Mr. T. W. Stanton gives the title "Pugnellus" to the sandstone and equivalent purplish limestone at the top of the Carlile shale; but it has not seemed advantageous to follow him in the present report, as the fossil shell, Pugnellus, which he found characteristic in another district, is of rare occurrence in the region here described.

HETEROCERAS NEBRASCENSE. Natural size.

The perfect individual has several coils like those at the top of the figure and a single open coil at the bottom, as in this instance, but the shell is usually found in fragments a few inches in length. It is characteristic of the Tepee zone of the Pierre shale.

1

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INOCERAMUS CRIPSII AND SCAPHITES NODOSUS, FOSSIL SHELLS CHARACTERISTIC OF THE TEPEE ZONE OF THE PIERRE SHALE.

Inoceramus cripsii (Fig. 1) is a bivalve shell shaped something like the fresh-water clam. The valves may be found separate or together. The individual figured is of moderate size.

Scaphites nodosus is a coiled shell, and Fig 2 shows a large individual.

he is able, by the aid of the preceding descriptions, to recognize the particular formation occurring at the locality in which he is interested. For his aid a scale of heights has been added to the diagram at one margin, the zero mark being placed somewhat below the top of the Dakota group, at about the level where a water-bearing bed is to be

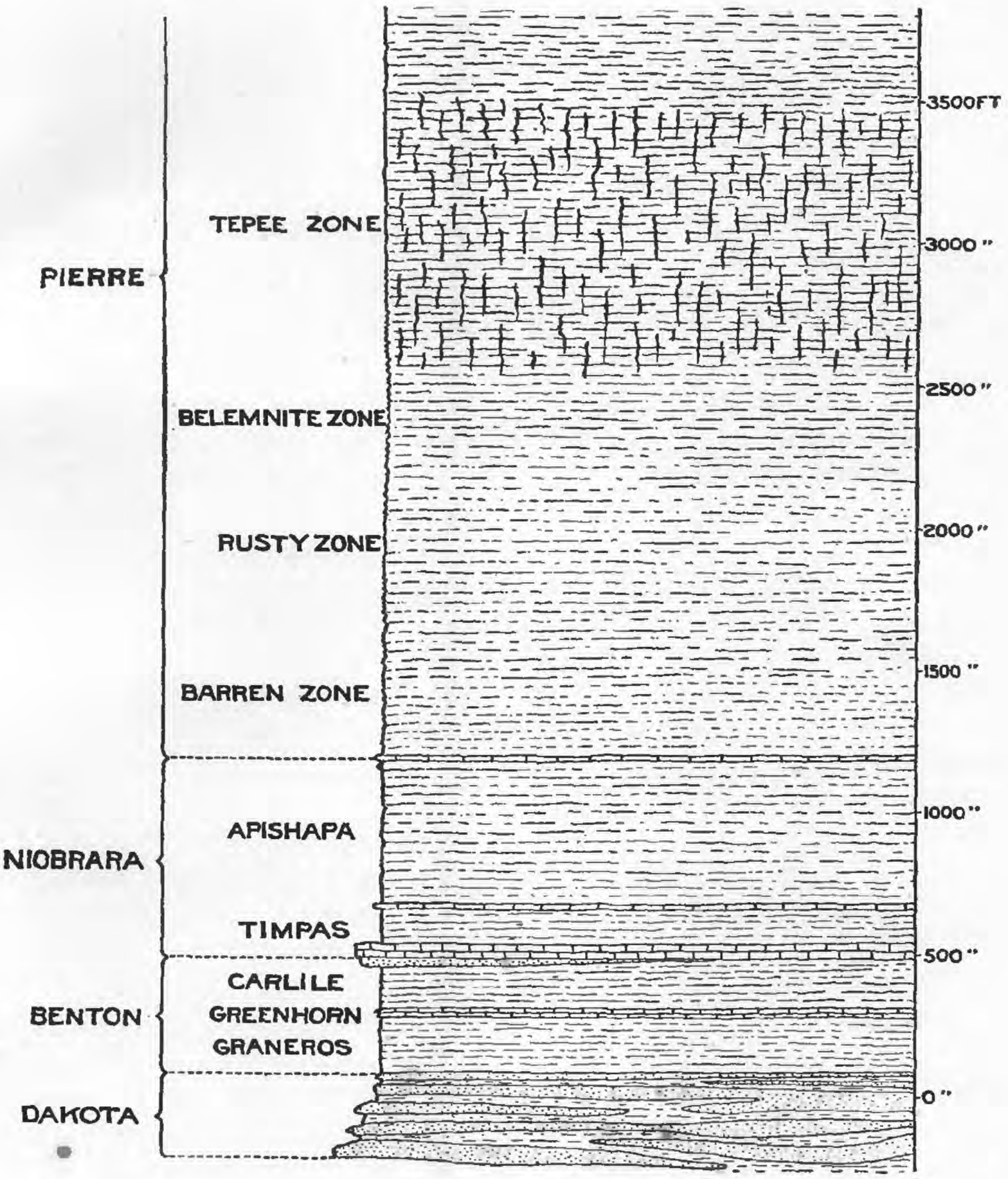


FIG. 46.—*Diagrammatic section of the Cretaceous strata* (except the Fox Hills group), showing the relative thicknesses of the formations. Shales are indicated by broken lines, sandstones by dots limestones by oblong blocks. In the Tepee zone the vertical marks represent tepee cores, but are, more thickly set than in nature. Names of groups are given in the first column, names of formations and zones in the second.

expected. The higher gradations of the scale indicate the approximate depth of this water-bearing horizon below the corresponding elements of the rock series. For example, if one finds at his locality a whitish limestone made of heavy beds separated by only a few inches of shale, if he notes in the limestone the thick shell *Inoceramus deformis* (Pl. LX), and if he finds on its surface a number of the nodules figured in Pl. LIX, he recognizes the presence of the heavy limestone at the base of the Timpas formation, and then, from the scale on the diagram, may learn that the first water-bearing rock is 500 feet below him; if he finds about him the peculiar buttes of the Tepee zone he knows that a supply of water can not be reached at much less than 3,000 feet.

STRUCTURE OF THE CRETACEOUS ROCKS.

Originally the layers of Cretaceous sediment were nearly level. The sandy beds of the Dakota may have had considerable local inclination, but the shales and limestones above could not have received their wonderfully uniform distribution unless the floor upon which they were spread was smooth and even. At the present time, however, the beds have such attitudes that their originally level character might not be suspected but for their widespread uniformity of constitution. They have been subjected to disturbances of two kinds—the one affecting the whole area as a unit, the other the local details. Considering the attitude of the strata in the broadest way, they incline toward the east and north. The average eastward inclination coincides approximately with the slope of the plains; the northward is a little more rapid; so that the average direction of slope may be said to be somewhat north of northeast. It is a general law that the higher rocks are uplifted the more rapidly are they washed away by the action of rain and streams, and the operation of this law is well illustrated in the Arkansas district. Along its southern margin the shales of the Pierre, Niobrara, and Benton groups have largely disappeared, so that the Dakota sandstones are exposed at the surface. Along its northern margin parts or all of the Pierre shales remain, and in the intervening district the Apishapa, Timpas, Carlile, Greenhorn, and Graneros formations occupy the country in belts.

To this general fact of distribution there are many exceptions, as will presently appear, and these exceptions depend upon the second or local factor of disturbance. At many places the strata have been uplifted into domes, depressed into basins, or thrown into folds with alternate arches and hollows. For the most part these forms have been produced by the bending of the rocks, but to some extent the rocks have been fractured also, being divided by vertical fissures along which motion has taken place, so that one part has gone up or down with reference to the opposed part. Such displacements, or "faults," as the geologist calls them, are in some parts of the district very numerous, although of small amount, only 25 to 50 feet, but elsewhere they are measured by some hundreds of feet. In a general way the folding and faulting have been greatest in the western part of the district, but there were some disturbances of considerable importance near the eastern boundary of the State.

1

2

LUCINA OCCIDENTALIS AND INOCERAMUS SAGENSIS.

Lucina occidentalis (Fig. 1) is a small bivalve shell occurring in great abundance in the limestone cores of the Tepee Buttes. The figure shows a side view. Natural size.

Inoceramus sagensis (Fig. 2) is characteristic of the Tepee zone, but is rarely found in the limestone cores. The individual figured is young. The adult form spreads into a broad, smooth shield, often a foot in diameter.

A TEPEE BUTTE.

One effect of the local disturbance is to complicate the outlines of the belts of country occupied by the various formations. Instead of running directly from east to west across the district, they curve in and out in an intricate manner, and there are many isolated patches, so that the completed geologic map will be quite complex. Another effect is that the rocks often locally incline rather steeply in one direction or another, so that predictions in regard to the depth of artesian water made at one spot may require considerable qualification as regards another spot only a few miles distant. A detailed map to show the variations in depth of underground water will therefore be also somewhat complex.

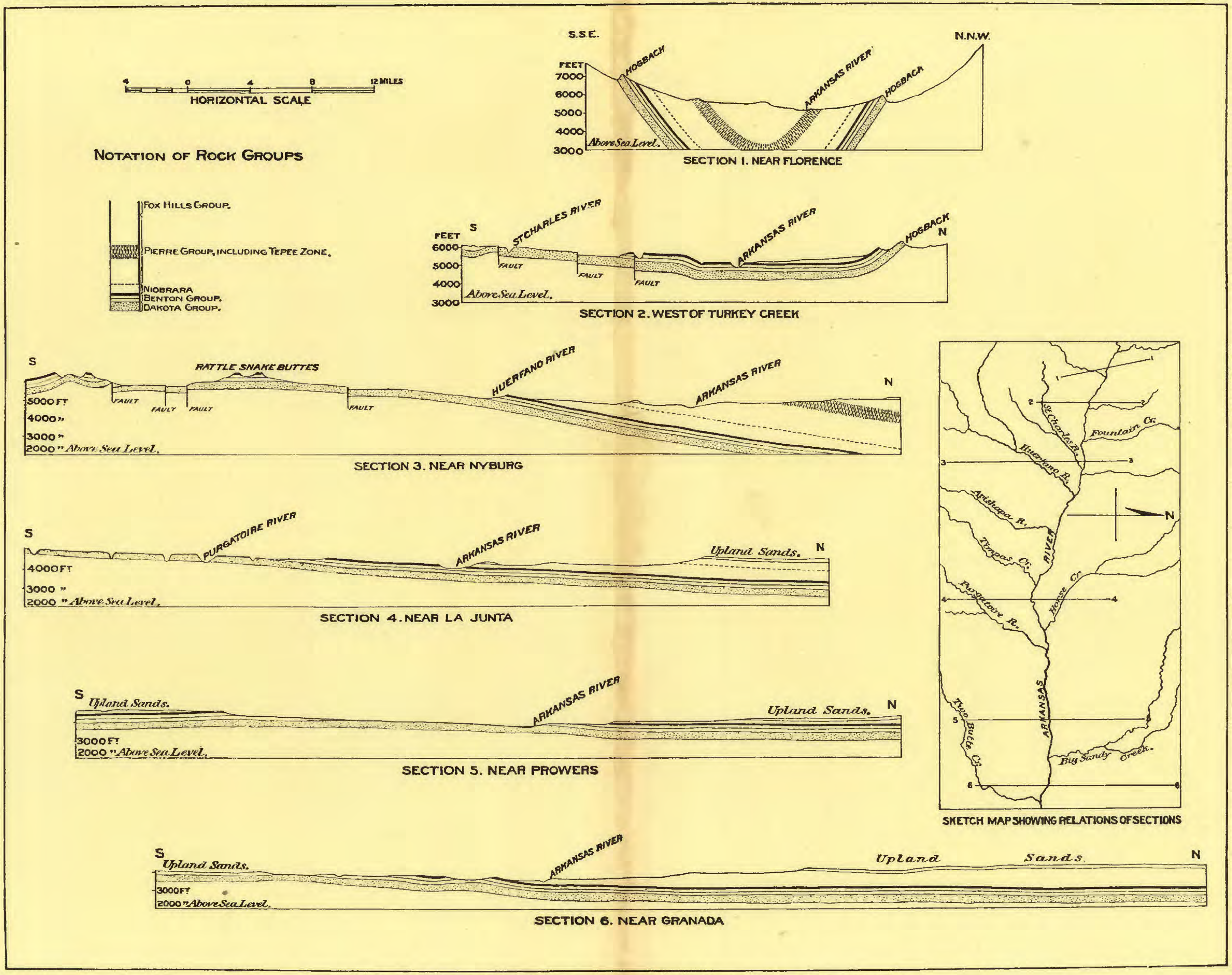
By reason of this complexity it has not seemed advisable to accompany this report by such approximate map as could be drawn at the present time, lest its unavoidable inaccuracies lead to costly errors in the search for water; but a number of sections have been prepared illustrating some of the broader features of the local rock structure. These are grouped together under Pl. LXVIII.

If a very deep and long trench, with straight sides, were dug across the country, all of the rock strata would be cut in two and their arrangement could readily be seen. A picture of one of the sides of such a trench would be called a geologic section and would have a general appearance similar to the sections of the plate. In these sections vertical distances are represented on a much larger scale than horizontal distances, so that there is a certain amount of distortion, and in that respect the impression conveyed by the uppermost section may be somewhat misleading. The difficulty could not be avoided without encountering another, for if the vertical scale were made the same as the horizontal the thickness of certain formations would be too small for representation. The sketch map at the right shows the approximate positions of the sections with reference to the rivers and creeks of the district, and the sections themselves are so arranged that points having the same latitude fall in the same vertical line. The Dakota sandstone is distinguished from all other formations by marking with dots the band which represents it, and all formations below the Dakota are omitted, so that attention may be concentrated on the rocks associated with the water supply. Above the Dakota band is a white space representing the Graneros shale, a thin line in the position of the Greenhorn formation, a second space representing the Carlile shale, and a heavier line representing the limestone at the base of the Timpas formation. The Timpas and Apishapa formations are not distinguished, but the top of the Apishapa, or the boundary between the Niobrara group and the Pierre, is indicated by a broken line. The broad space above, representing the Pierre, is interrupted by a special notation of short lines showing the position of the Tepee zone.

The first section is a peculiar one, crossing a spot where the rocks are arranged in the form of a basin. This basin is oval, and includes the Florence oil field. The second section runs northward from the St. Charles River below the Three R ranch, crossing the line of hogbacks a few miles west of Turkey Creek. In the southern part of the section the Dakota sandstone lies at the surface of the country, and is broken across by several faults. Farther north it is overlain by other formations, and for much of the distance the Timpas limestone is at or near the surface. The canyon of the Arkansas River is cut through the Timpas limestone and the Carlile shale, reaching down nearly to the Greenhorn limestone. The third section shows a broad tract south of the center, where the Dakota sandstone forms the surface of the country. The sandstone is there uplifted in a great dome, through which the Huerfano River and its branch, the Cucharas, pass in deep canyons. The southern edge of the dome is also traversed in a canyon by the Apishapa River. On top of the dome stands an island-like mass of Benton shales, capped by small remnants of the Timpas limestone and constituting the Rattlesnake Buttes. Round about the dome is a line of cliffs marking the outcrop of the Timpas limestone, and back of the cliffs is usually a table-land sloping outward, though these characters are interrupted by reason of various faults and small flexures. The line of cliffs crosses the Huerfano River a few miles above Undercliff. Northward the rocks continue to descend, and the surface is occupied successively by the Niobrara and Pierre shales. The Arkansas River flows through an open valley in the lower part of the Pierre. Farther eastward the structure of the rocks is in general more simple and their inclination more gentle. The fourth section traverses at the south a low dome through which the Purgatoire River makes a long, deep canyon, and there are many other canyons occupied by tributaries of the Purgatoire. The southern part of this dome does not appear in the section, but only its northward slope. The Timpas limestone occupies bluffs on both sides of the Arkansas River at La Junta, and is covered toward the north by Niobrara and Pierre shales. In the fifth section the sandstone is uncovered near the middle and covered at either end. In the sixth it lies near the surface at the south, but descends deeply toward the north. It is to a certain extent true of all the sections, but especially of the last, that many subordinate bendings and dislocations of the strata are omitted for lack of full information.

UPLAND SANDS AND GRAVELS.

There is one other formation of importance with reference to the water supply of the region. It overlies the Cretaceous formations, resting in different places upon each of them, and it differs from them conspicuously in that the particles of which it is composed are, as a rule, not cemented together, but lie loose, as sands, gravels, and loams or marls. An understanding of the relations of this formation can be most readily reached by considering its history.



SECTIONS ACROSS THE ARKANSAS VALLEY FROM SOUTH TO NORTH, SHOWING THE ARRANGEMENT OF THE CRETACEOUS ROCKS.

The bending and faulting of the Cretaceous rocks and the general uplift which inclined them toward the east and north took place long ago. From the moment of the emergence of the rocks above the sea they were attacked by eroding agents. By alternate wetting and drying, freezing and thawing, the coherent particles near the surface were loosened. Rains washed them to stream channels, and the streams carried them to the distant sea, and thus the surface of the land was worn away. It is not difficult to understand this process, for a little observation will show that it is now in progress in the same region. If one digs down a few feet or a few yards into the Cretaceous shales, he finds them quite compact; but at the surface, where shower and frost have acted, they are reduced to an incoherent earth. Whenever a storm comes some of this earth is washed away from the land and carried by the creeks to the Arkansas River, the Arkansas delivers it to the Mississippi, and the Mississippi to the ocean. The mud in the river water is the waste of the land in process of transportation.

It is evident that however rapid this process may be, or however long the time during which it is continued, the land can not be worn down below the level of the ocean. Geologists express this law by saying that the ocean is the "base level of erosion." Moreover, as streams run slowly where their beds are inclined gently, and with comparative swiftness where their beds are steep, and as mud and sand constantly settle out of slow-running water, erosion can not progress rapidly unless the river channel and the stream channels have a certain amount of slope. When the degradation of the country has gone so far that all the slopes are gentle, its progress is comparatively slow. The tendency, therefore, is to reduce the whole region to a system of shallow valleys with gently sloping sides, traversed by streams whose beds incline toward the great trunk line of transportation, the Mississippi. It was probably reduced to this condition in the period of erosion just mentioned as following the uplift and disturbance of the Cretaceous rocks. We may think of the surface of the Great Plains as then more nearly level than it is now.

Eventually the process of erosion was completely arrested, and processes of deposition took its place. This change was brought about by some modification of conditions which is not yet clearly understood. Perhaps the plains region was depressed at the west, and the slopes thus rendered so gentle that the streams could no longer carry off the detritus which came from the mountains, and it was deposited on the way. Perhaps a barrier was lifted at the east, so that the base level stood higher. Whatever the cause, the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions, and they thus came to flow in succession over all parts of the plains and to distribute their deposit widely, so that the whole plain in the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains. It is thought by geologists who have studied the formations of Kansas that lakes were formed there during a portion or the whole of this period, so that the sedimentation was from still water instead of from the currents of sluggish streams. It is probable that during part of the period such lakes extended into northeastern Colorado, but the principal work within the field of our reconnoissance appears to have been done by running water. In a general way, the deposits seem to have been heavier toward the northeast than toward the south and west, but the difference was not great. The range in observed thickness is from 50 to 200 feet.

The chief material is coarse sand, and this is arranged in irregular beds with much oblique lamination, such as ordinarily results from the work of streams. In the sand are occasional pebbles, and these are in places gathered into distinct beds of gravel. Except near the base of the formation the pebbles do not include fragments of the Cretaceous rocks of the plains, but are of harder materials, able to survive the wear and tear of a long journey. North of the Arkansas River they seem to have come wholly from the Rocky Mountains, and they resemble the material now brought by Fountain Creek from the vicinity of Pikes Peak. South of the Arkansas they include also certain volcanic rocks which occur in the Spanish Peaks and neighboring mesas.

Where the sand rests on the Cretaceous rocks it is often bound together with a limy cement, so as to constitute a sandstone, but this phase has usually a thickness of only 1 or 2 feet. At several places on the north side of the valley zones of cementation were seen at higher levels, the calcareous cement being so abundant as to close all interstices, converting the sand into a calcareous sandstone, or sometimes into a sandy limestone. At the northeast, in the valleys of various creeks tributary to the Smoky Hill River, clays, marls, and other fine-grained beds alternate with the sand in the lower part of the formation, and these are probably continuations of the lake deposits observed in Kansas.

Near the top of the sand are occasionally found thin, broad, lens-shaped bodies of a fine earth called "loess," and the same material overlies the sand at many places. Loess is a peculiar material, and its origin is often doubtful; in some instances it has been ascribed to the action of the wind, in others it has been referred to deposition in still water. It may be that the deposits of this region have been formed partly in the one way, partly in the other, but the chief agent appears to have been wind. The dust raised by violent windstorms, such as are familiar to the residents of the district at the present time, must somewhere descend to the earth, and if it falls on land occupied by vegetation the wind does not again lift it. The soil thus formed has an open texture, so that it absorbs most of the rain falling upon it, and is thus protected from the washing effect of rain water running over the surface.

So by streams, lakes, and winds there was spread a great mantle of sand and silt, by which the minor valleys and hills were buried from sight and the Cretaceous formations were at the same time concealed.

Eventually deposition was in turn arrested and erosion resumed. The streams, which had been shifted from one course to another so as to occupy successively and many times each part of the surface, became fixed in position as soon as changing conditions caused their waters to erode once more. The cause of the new change was probably renewed uplift—a general elevation of the plains region, which was greater at the west than at the east, so that the eastward slopes were increased. Streams flowing in that direction acquired a greater velocity, and were able not only to carry forward all the detritus with which the storms fed them, but also to wear their beds and deepen their channels. As the stream channels were worn slowly down the earth of adjacent slopes was washed into them, and thus broad valleys were opened out. Then from the uplands between the valleys more or less of the sandy formation was washed down, so as to form a coating over the slopes of the valley. As the material occupying the slopes is identical in character with the great deposit whence it was derived, it is now hard to distinguish them, and the name "upland sands and gravels" is applied alike to the original and the derivative deposits.

At a later epoch the land was lifted still higher and erosion greatly accelerated, so that the stream valleys were deepened several hundred feet without being opened so broadly as before. This later action gave somewhat definite limits to the upland formation, which now constitutes a high plain or plateau, separated from the greater stream valleys by a line of bluffs, and along this bluff line the Cretaceous formations are usually to be seen in contact with the overlying sand.

On the northern slope of the Arkansas Valley the upland sands approach the river within 5 to 15 miles, their limit being marked by bluffs from Pueblo to the Kansas boundary. The bluff line is broken only by the valleys of tributary streams. The reports of other geologists indicate that the formation extends northward for many miles, but from personal observation the writer can only say that it passes everywhere beyond the field of his reconnoissance.

On the southern slope of the valley the formation lies much farther back from the river, having been seen only in the southern part of Prowers County, at distances of 12 to 15 miles, and at a somewhat greater distance in the southern corner of Bents County. Thence it extends to an unknown distance southward, and the study of topographic maps indicates that it also extends toward the southwest in Las Animas County.

TERRACE SANDS AND GRAVELS.

The broad valley dug by the Arkansas and its tributaries since the spreading and respreading of the upland sands and gravels has a depth of from 400 to 800 feet. Its sloping sides are composed chiefly of the shales and other rocks of the Cretaceous system, but there are many local belts of gravel and sand. Except where the sand has been disturbed by the wind, these belts are flatter than the neighboring slopes, and they are usually sharply limited toward the river by steep slopes or bluffs so as to constitute benches or terraces. Much of the irrigated land of the valley lies on these terraces. In some cases the gravel and sand are covered by a few feet of loam, and their presence is then discovered only through wells or by an examination of the terrace at its margins.

These terraces were all made by the river and its branches during the progress of the excavation of the valley, and it is easy to understand them if one notes the present condition and habits of the river. The river is a great carrier of mud, sand, and gravel. This work it performs chiefly at time of flood, and the finer part of its load can then be seen in the water as the torrent rolls along. The gravel can not be seen in motion as it is dragged and rolled along the bottom in the deeper parts of the channel, but its presence may be noted here and there at low stage.

On the outside of each curve of its course the torrent digs into the

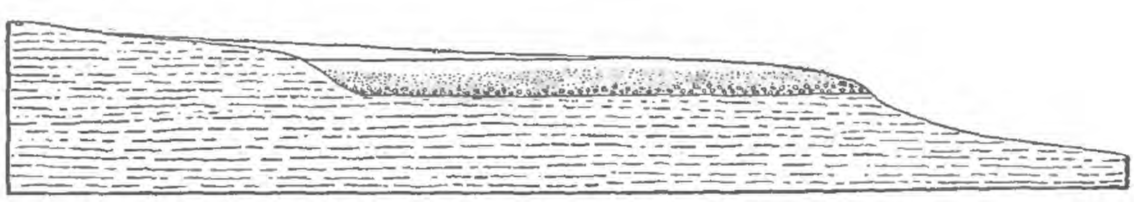


FIG. 47.—Diagrammatic section across a terrace. The dots show sand and gravel, the broken lines bed rock.

bank, so that the river encroaches on the land; but the channel does not grow broader, because in the quieter water on the inside of the curve some of the sand settles from the water, and new land is thus built up. At first the accumulating sand makes only a shoal, but as the main current works farther and farther away, sand and mud are gradually added until the level of the bottom land, or flood plain, is reached. In fact, the whole flood plain of the river has been formed in this way. Some of the bends lie wholly in the flood plain, so that what they dig out is merely alluvium that the river had previously deposited; other bends touch bed rock, and by digging in that make the flood plain broader.

As the stream thus gradually shifts its channel all over its flood plain, it leaves behind an assorted deposit. The lowest layer is gravel, and this rests directly on the Cretaceous bed rock; then comes sand, and, above the sand, clay or loam.

Each of the terraces of the valley slopes is part of a river flood plain, formed when the valley had been dug only to that level. The oldest are those lying highest, and the newest of all is so near the modern flood plain that it is called the "second bottom." As a result of this origin the terraces have the general structure indicated in the diagram (fig. 47). Ordinarily the thickness of the deposit is not greater than the maximum depth of the river during high water. The newer terraces have loam, sand, and gravel. The older have often lost the loam and sand, especially near their bluff edges, and retain only the gravel. In a few cases the thickness of the deposit is greater than the high-water depth of the river, showing that the digging of the valley was interrupted by short periods of valley filling.

Most of the terraces have a gentle grade toward the river, the outer part having been somewhat washed away by rain and the inner part built up by material washed from higher slopes. They have also a gentle grade eastward parallel to the river, and this grade was given to them chiefly in the process of their formation. It is possible, however, that part of it has been caused by a slow rising of the western part of the plains. An attempt has been made to identify each of the stronger-marked terraces from point to point, so as to learn its original extent and position, and this investigation has shown that they descend eastward more rapidly than the present grade of the river.

While the Arkansas was making its valley, each tributary river was engaged in a similar work, and similar systems of terraces record the stages of its progress. At river junctions the terraces of two valleys are frequently seen to unite.

DUNE SANDS.

Yet another geologic formation deserves mention in this place by reason of its relation to water supply. When the wind blows over a bed of dry sand that is not protected by vegetation, grains of sand are drifted along over the ground. Any little obstruction, by checking the wind, tends to stop them, and when they have once begun to accumulate at any point their own heap acts as an obstruction, creating behind it an eddy of the wind, where the grains more rapidly lodge. On the windward side of the hill the wind is a little accelerated, so that there is a tendency toward excavation. By excavation on the windward side and accumulation on the lee side the hill of sand slowly travels in the direction of the wind's motion. Such traveling hills are called dunes.

On the broad plains underlain by the upland sands and gravels there are a number of local districts where the sand is fine enough to be moved by the wind and the vegetation is too scant to hold it. It is there blown about and gathered into dunes. If the wind blew as freqnently and as strongly from one direction as another, the hills would make no progress; but all through the district the prevailing winds are from the northwest, and the sand hills therefore travel toward the southeast. The most important district of this class occupies a portion of the northern slope of the valley, having its southwestern limit near Carpenter Spring and the Langford ranch, its southeastern near Antelope Springs, and extending thence northward. The whole surface of this district, so far as explored, is a system of hills and hollows without drainage by streams, so that all the rain which falls on it and is not evaporated from the surface is absorbed by the sand. There are a few localities where the terrace sands have been disturbed by the wind, but they are comparatively unimportant and need not here be described.

Another source of dune sands is found in stream beds. Nearly all the streams of the district carry sand along their beds and build it into flood plains. Sometimes the sand is combined with so much clay that after it has become dry the grains stick together; but in other instances the streams carry little clay, and the sand, after drying, is quite loose. Under such circumstances the parts of the stream beds laid bare at low water, being without vegetation, are subject to the attacks of the wind. The sand is blown on the banks and built into dunes, and the dunes move slowly across the country. Two streams of the northern slope give rise in this way to broad belts of dunes. Black Squirrel Creek, the principal branch of Chico Creek, rising among the upland sands, carries their material southward and yields it to the wind at various points. The belt of dunes thus created blends in part with the broad tract of dunes just mentioned to the northwest of the Langford ranch. Big Sandy Creek and its principal tributaries similarly head in the upland sands and flow southward, and the immense body of sand carried by them furnishes to the wind the material for a broad belt of dunes following their eastern banks. In a similar way the sands brought by the Arkansas River are built into dunes along its south bank from La Junta eastward. The general course of the river is there from west to east, and as the prevailing wind blows toward the southeast the sand moving from the river bed in that direction, rises over the southern bank. The belt of dunes thus created is crossed every few miles by a stream running northeastward to join the Arkansas. None of these streams are perennial. The larger of them flow several months in each year, and all flow during periods of exceptional storm. As the sand is blown into their beds it tends to clog them, but the storm waters clear out the channels and carry the sand back to the Arkansas. Thus there is a perpetual conflict between the winds carrying the sand southeastward and the streams carrying it northeastward. As a result of this conflict, the sand belt, which would doubtless otherwise be much more extensive, is limited to a breadth of 3 or 4 miles.

ARTESIAN WATER.

Underground water falls into two general classes. It may flow through a porous bed which is continuous to the surface of the ground, in which case the position of its upper surface varies with the supply; or it may flow through a porous stratum confined between impervious strata, in which case it usually occupies the entire stratum and presses, not only downward on the limiting impervious rock beneath, but upward against the impervious cover. When water of the first class is reached by a well it retains its natural level within the well. When a well is put down to water of the second class the water rises somewhat within the opening, the height to which it rises being determined by its original pressure against the covering rock. If the conditions are favorable it may rise to the surface of the ground and flow out. Water which does not rise in the well is called "ground water." For the class of underground waters which do rise usage is divided. By some writers all such waters are called "artesian;" by others the term is limited to such waters as have sufficient head to outflow at the surface. It will be convenient in this paper to conform to the first-mentioned usage, defining artesian water as that which presses upward as well as downward on the walls of its conduit, so as to rise toward the surface, or perhaps above the surface, when a way for it is opened. The wells which draw water from such a source are ordinarily described as "flowing" when the water is naturally discharged at the surface, and as "pumping" when the head is not sufficient for a natural discharge.

GENERAL CONDITIONS.

That underground water may be artesian, two things are essential: First, that the porous bed receive its supply at a point or in a region where it lies comparatively high; second, that it be inclosed by comparatively impervious beds. If the inclosing beds permit no water to escape, and completely surround the reservoir except in the region of supply, then wherever the reservoir is tapped by a boring the water will rise to the height of the lowest point of supply. This ideal condition is never realized. The rocks called impervious are not absolutely water-tight, but only relatively so; and few water-bearing rocks are completely inclosed by rocks of the impervious class. The head of artesian water is therefore somewhat lower than the region of supply, and it may be much lower.

Usually there is a slow but continuous movement of water through pervious strata from the district of supply downward to points of natural discharge; and the pressure on the covering rocks is largely regulated by variations in the resistance to the water's movement, depending on the texture and thickness of the porous bed. In places where the bed is relatively thin or its texture relatively fine the resistance to flow is relatively great, and this resistance operates to increase the head at points nearer the source.

The practical value of a body of artesian water also depends on the quantity which can be continuously supplied to wells, and this, in turn, on the size and character of the conduit, on the freedom with which water is received in the region of imbibition, and in some cases on the rainfall. The value depends in part also on the quality of the water, on its depth beneath the surface, and on various other factors affecting the cost of securing it. The natural circumstances affecting the availability of artesian water are ably and comprehensively treated in the Fifth Annual Report of the United States Geological Survey, in a paper on "The requisite and qualifying conditions of artesian wells," by Thomas C. Chamberlin.

WATER OF THE DAKOTA SANDSTONE.

In the district under consideration the only artesian water of demonstrated value is that contained in the Dakota sandstone. It is probable that there is no other formation from which water can be profitably obtained, and it may be asserted with confidence that no other compares in importance with the Dakota sandstone.

GATHERING GROUNDS.

The water is received by the Dakota sandstone in the region where that rock outcrops at the surface, and also in the region where it is covered only by the upland sands. The regions of outcrop which may be supposed to affect the supply in this district comprise, first, the line of so-called hogbacks; second, a number of broad outlying tracts at various points on the plains. The hogbacks are a chain of high ridges, overlooking the plains and separated from the mountains by a chain of valleys and parks. From Colorado Springs they run southward to the canyon of Turkey Creek, then westward past Glendale to a point just north of Canyon, and southward and southeastward to a point a few miles northeast of Beulah, where they turn southward to the Three R ranch. They are there interrupted, but reappear in a few miles and continue along the base of Greenhorn Mountain and beyond. In some places the chain includes several parallel ridges, elsewhere but one. The chief ridge is everywhere definitely associated with the Dakota sandstone, and marks the place where the sandstone is turned up at the foot of the mountains. The relation of the sandstone to the hogbacks is illustrated by fig. 48, and also by sections 1 and 2 of Pl. LXVIII.

In the figure the Dakota sandstone is represented by a broad line ending in the hogback H, and the lower slopes of the Wet Mountains appear at W. Here, as elsewhere, the sandstone ridge is separated from the mountains by a valley, so that the sandstone does not receive the water of mountain storms and snow banks, but only that which falls on the narrow ridge. At this particular point the sandstone belt, from H to I, is about a mile broad; from I to T the formation is covered by the Benton shales, and from T to S by the Timpas limestone, except where divided by the Arkansas canyon, A. At some points the width of exposed sandstone is greater, but generally it is less, and the average is not more than a mile. Where it is narrow, the slopes are so steep that a large share of the storm water runs off and the sandstone can imbibe but little; but the broader parts of the belt have gentler slopes, more or less covered by a blanket of sand, in which the rain water is stored for a time, and from which it may be slowly absorbed by the sandstone.

The most westerly of the outlying areas lies just outside the hogbacks in the region drained by the head waters of Peck Creek and Rock Creek and traversed by the main branch of the St. Charles River. It has an area of 50 or 60 square miles. Another district begins about 20 miles south of Pueblo, includes nearly the whole of the Virgil and St. Vrains grant, and extends thence southward and southeastward. Its extent is approximately 500 square miles, and the slopes are sufficiently gentle to make the conditions for absorption favorable. A third tract of importance has its northern margin at the Arkansas River between Las Animas and the mouth of Mud Creek, and extends thence to the south and southeast. It borders the Purgatoire River on both sides to Bents Canyon and beyond, and includes large areas drained by Blue, Caddoa, Mud, and Clay creeks. Its extent is not fully known, but the total area is not less than 1,000 square miles. Contiguous to this is a district of unknown extent in which the Dakota sandstone is covered by the upland sands, from which it may receive water. Beginning at the head waters of Clay and Wolf creeks, the district extends southward and southeastward across Two Butte Creek and probably to the basin of Horse Creek.

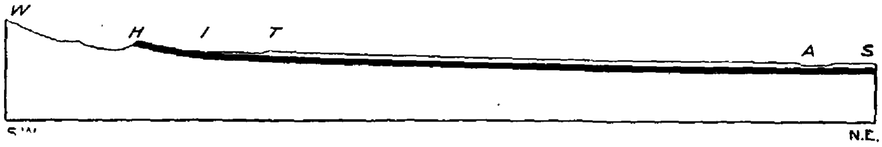


FIG. 48.—Section from the Wet Mountains to the Arkansas River, along a line west of Red Creek, showing the relation of the Dakota sandstone to the surface of the country. Scale, about 4 miles to the inch.

It is impossible to say what share of these areas contributes water to the sandstone. In part they are occupied by the upper layers of sandstone, which are so fine textured as to receive little water. The irregularity of the sandstone beds is so great as to raise the question whether all of the porous beds exposed to the rain are of such horizontal extent as to carry water to the deeply buried portions of the formation. Such considerations make it impossible to estimate the amount of water which may annually be imbibed, and for the present at least it is useless to discuss the annual rainfall with reference to the extent of the gathering grounds.

CAPACITY.

Whether we regard the Dakota formation as a reservoir containing a body of water from which a supply may be drawn by wells, or as a conduit through which water is flowing, its capacity depends on the thickness of the water-bearing sandstone strata and on their porosity. Some experiments conducted by Mr. G. W. Stose, of the Geological Survey, indicate that the beds of more open texture are able to absorb

18 per cent of their volume of water.[1] In the western portion of the district the thickness of rocks having approximately this capacity is estimated at from 150 to 175 feet; farther east it is considerably less, but in the gathering grounds at the south, where the rocks are exposed to direct examination, it is probably nowhere less than 75 feet. Taking the smallest figure as a limit and applying the factor of porosity, we find it probable that all portions of the district in which the sandstone constitutes a deep-lying formation have beneath them at least 12 cubic feet of artesian water for each square foot of surface. This statement views the Dakota sandstone as a reservoir, and has no direct bearing on the quantity that can be obtained from the rock at any point except that it affords a guaranty of practical permanence to any supply which may be derived.

The amount of water flowing from a well depends in part on the height of the point of discharge as compared to the head of the water, or the pressure which it naturally exerts on the overlying impervious rock; but the amount which may be obtained by pumping depends entirely on the capacity of the rock as a conduit—that is, on its thickness and the resistance which its texture opposes to the free flow of water. The resistance of the rock, or the friction produced by water in passing through it, might be investigated experimentally in the laboratory, and such an inquiry would be valuable; but a more practical test is afforded by the experience of those who have already tapped the formation by wells and derived a supply from it. A well put down by the town of Rocky Ford gave a measured flow of 68 gallons per minute, or 98,000 gallons per day. A second well in the same town is reported by Mr. C. W. Cressy to yield 157, and a third well 60 gallons. I am informed by Mr. A. J. Hottel, of the Lamar Flouring Mill, that 35,000 gallons are pumped daily from the well at that mill, and that the limit of supply has never been reached, although the head has been drawn down to 150 feet. The first well put down by the Atchison, Topeka and Santa Fe Railroad at La Junta gave a small flow at the surface and yielded 60 gallons per minute by pumping.

There are two considerations of importance affecting the use of such data as have been cited above in estimating the supply to be expected at points heretofore untested. The first is that these wells, like nearly all other wells of the region, end in the first water-bearing sandstone met by the drill. There is reason to believe that in most localities deeper boring would discover a second and often a third sandstone carrying artesian water. Where such lower beds have been examined along the outcrops of the formation their characters indicate that they may prove as valuable as the upper.[2]

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[1] Three specimens were found to absorb respectively 12, 16, and 26 per cent of water.

[2] Since this passage was written a partial verification of its prediction has been reported. Two wells recently drilled at La Junta have penetrated the whole of the Dakota formation, finding two water-bearing sandstones separated by a shale bed 130 feet thick. The lower yields the greater volume of water. One of these delivers 50 gallons per minute at about the level of the first La Junta well; the other delivers 20 gallons at a level 135 feet higher.

The second consideration is one of limitation, and pertains to the enlargement of local supply by increasing the number of wells. The experience of many communities has served to demonstrate that every well from which artesian water is drawn diminishes the head or pressure in the neighboring portions of the water-bearing formation, so that a well bored near it can not obtain so much water as it otherwise might. Reciprocally, the drawing of water from a new well diminishes the available supply for all other wells of the vicinity. Where the peculiar value of a flowing well has led to the sinking of a series of other wells in the immediate vicinity, it has always been found that the flow of the older wells is diminished, so that eventually only wells occupying the lowest ground retain sufficient head to discharge at the surface. Pumping then usually follows, with the result that all natural overflow is stopped; and from the continued lowering of the head the cost of bringing the water to the surface gradually increases. If the inhabitants of this district are wise they will profit by the experience of other communities and limit their expectation as to the quantity of water which can be derived from the artesian source beneath. Drawn upon with moderation, it will serve many uses at moderate expense and be of great practical value; but if it is pumped to the extreme limit the head will be drawn so low as greatly to increase the expense of bringing it to the surface, and the yield will not be correspondingly enlarged.

DISTRIBUTION.

The regions already indicated as gathering grounds for artesian water are also to some extent regions available for its exploitation. The sandstones are to such an extent separated by impervious shales that a well started in one of the upper members of the group may, by passing through a shale bed, reach a lower sandstone in which the water is under pressure. This is in general true near the northeastern limit of the area on the St. Charles River, near the northern, western, and southern limits of the area bordering the Huerfano and Apishapa rivers, and near the northeastern, northern, and northwestern limits of the area extending from the Purgatoire River to Clay Creek. In all such cases the depth from the surface will be small, not exceeding 200 or 300 feet.

From these areas northward the depth of the artesian sheet beneath the surface gradually increases, but the rate of increase is irregular, and there are doubtless many localities in which for short distances the depth diminishes northward. The line along which the depth is about 1,000 feet may be approximately and provisionally sketched as follows: It passes through the southwestern part of Pueblo and runs a little west of north up Dry Creek Valley to the vicinity of Blue Hill Spring. In the opposite direction it runs southward, and then more easterly to Undercliff, crosses the Apishapa River not far from the mouth of Mustang Creek, passes north of the Arkansas River a few miles above

Rocky Ford, and continues north of the river to the Kansas line. It is probably as much as 15 miles north of Lamar, but is comparatively near the river in the vicinity of Granada. Between this line and the gathering grounds already mentioned the depth of the artesian water is believed to be everywhere less than 1,000 feet. Farther north it is more than 1,000 feet.

In fig. 49 a rough map is given of the artesian district. A subdistrict is shown in which the depth of water is estimated as less than 1,000 feet, and another in which the depth is estimated as between 1,000 and 2,000 feet. North of the 2,000-foot line, and in an oval tract about Florence the depth to the Dakota water is supposed to be more than 2,000 feet. I confess that I have drawn this map with much reluctance, because it is impossible in such delineation to give adequate expression to doubt, and the data at hand are too imperfect to fix the lines definitely except at a few points. When the region has been thoroughly

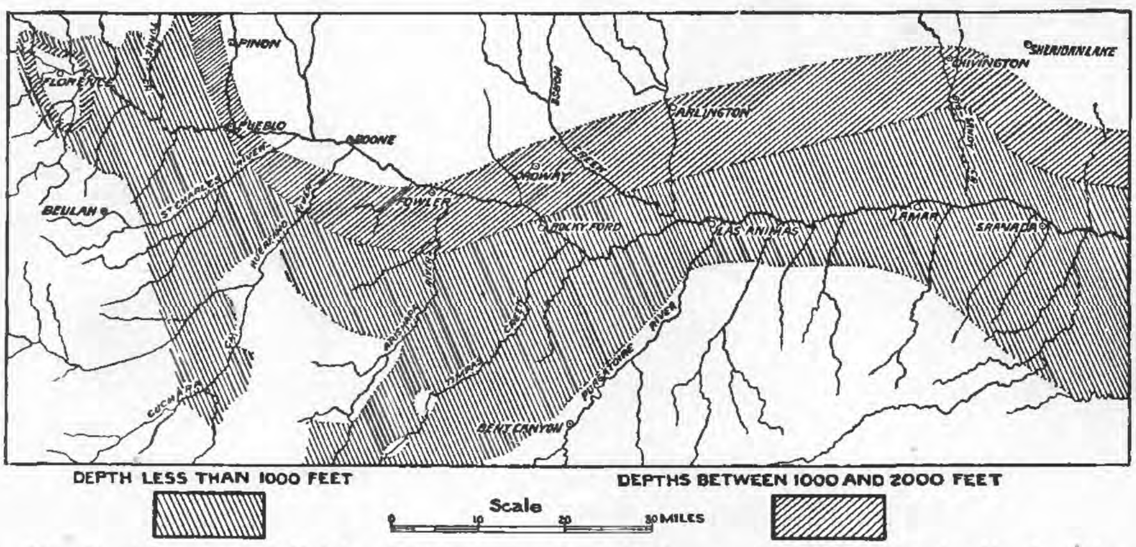

FIG. 49.—The artesian district, showing approximately the area in which the water lies less than 1,000 feet below the surface, and the belts in which its depth is between 1,000 and 2,000 feet.

surveyed, the free-curving boundary lines of each belt as here drawn will be replaced by more sinuous lines, and doubtless the general position of each one will be in some parts materially changed. The reader is warned that he must place no reliance on the local details of the map, but regard it merely as the expression of certain general facts as to the accessibility of the artesian water. The area in which artesian water is available at depths of less than 1,000 feet is nearly 4,000 square miles, and the corresponding area of depths between 1,000 and 2,000 feet is about 1,500 square miles.

The determination of the areas in which the water may be expected to reach the surface without pumping is a more difficult matter. It depends partly on the comparative porosity of the rock in different regions, a character which can not be directly observed; and for this reason trustworthy prediction can not be carried far in advance of experimental boring. There is, however, a general principle in regard to it which may well be emphasized, for the reason that it is too often disregarded. The absolute head of artesian water, or the height above sea level to which it will rise, depends on conditions existing in the water-bearing rock, and is altogether independent of the local configuration of the ground. It is ordinarily legitimate in any locality to think of that head as a horizontal plane, which may lie beneath the surface of the ground or above it. If the top of a well is below that plane, the water flows; if it is above the plane, pumping is necessary. Therefore, as a rule, it is in each locality more advantageous to start wells on low ground than on high, provided the circumstances under which the water is to be used are such that it will be specially advantageous to have it naturally delivered at the surface.

QUALITY.

The quality of a natural water depends on the character and amount of its impurities, and also, with reference to some uses, on its temperature. Impurities are classed as organic and inorganic, the organic being specially objectionable because they may include the germs of disease, the inorganic being advantageous or disadvantageous, according to the use to which the water is to be applied.

The water derived from the Dakota sandstone is practically free from organic matter and is probably entirely free from living organisms. This is a common character of artesian waters, which are effectually filtered in their long passage through the rocks. Of inorganic matter it contains a moderate amount, but sufficient to place it in the class of mineral waters. In 1,000,000 parts of Mississippi water there are dissolved about 170 parts of various minerals; in the same quantity of St. Lawrence River water about 160 parts. Four analyses of water derived by wells from the Dakota sandstone show 888, 1,341, 1,377, and 2,505 parts of dissolved minerals to 1,000,000 parts of water. The mineral impurity of the Dakota water is thus seen to be from 5 to 15 times as great as in the case of the great rivers of the country. The character, as well as the quantity, of the dissolved impurity varies from place to place, and also from bed to bed, as the different sandstone layers are penetrated. It is stated that in drilling the Grand Hotel well at Pueblo a comparatively pure water was found in an upper bed, and that the strong mineral water now flowing comes from a lower bed. Analyses show that the water of an upper bed obtained by the wells at Rocky Ford and La Junta is only moderately charged, but the water obtained in that district from a lower bed has not yet been tested.

TABLE I.—*Water analyses* (*results stated in ions*).

[Parts in 1,000,000.]

Substance.	I. Artesian well at Lamar.	II. Artesian well at La Junta.	III. Artesian well at Rocky Ford.	IV. Artesian well at Grand Hotel, Pueblo.
Chlorine (Cl)	33.3	54.0	28.2	277.2
Sulphuric ion (SO_4)	719.4	675.9	453.8	1,180.1
Carbonic ion (CO_3)	114.8	[a]169.6	[a]95.9	306.7
Nitric ion (NO_3)	....	Not est.	.4	....
Potassium (K)	....	6.4	7.0	79.2
Sodium (Na)	355.3	360.0	259.2	201.7
Lithium (Li)	....	Trace.	.5	18.3
Ammonium (NH_4)	....	([b])	.8	....
Calcium (Ca)	41.6	73.8	14.9	178.1
Strontium (Sr)	....	([b])	.5	....
Magnesium (Mg)	26.6	20.7	12.4	230.1
Iron (Fe)	....	[c].8	[d]2.8	34.2
Manganese (Mn)	....	[c].1	Trace.	....
Silica (SiO_2)	49.6	[e]16.1	[f]11.9	Trace.
Alumina (Al_2O_3)	....	Trace?	Trace?	....
Total	1,340.6	1,377.4	888.3	2,505.6

Substance.	V. Carlile Spring.	VI. Iron Duke Spring, Canyon.	VII. Little Ute Spring, Canyon.	VIII. Underflow well at La Junta.
Chlorine (Cl)	117.1	833.0	1,187.8	56.1
Sulphuric ion (SO_4)	238.4	136.0	140.1	550.6
Carbonic ion (CO_3)	459.7	1,217.0	1,109.6	[a]100.0
Nitric ion (NO_3)	....	....	....	Not est.
Potassium (K)	5.4	Trace.	Trace.	6.2
Sodium (Na)	253.8	1,154.4	1,385.7	143.2
Lithium (Li)	....	Trace.	Trace.	Trace.
Ammonium (NH_4)	....	....	....	....
Calcium (Ca)	153.6	214.3	150.0	140.4
Strontium (Sr)	....	....	....	([e])
Magnesium (Mg)	55.8	71.3	67.0	35.8
Iron (Fe)	2.5	Trace.	Trace.	....
Manganese (Mn)	....	....	....	....
Silica (SiO_2)	....	....	....	15.4
Alumina (Al_2O_3)	....	....	....	....
Total	1,286.3	3,625.0	4,040.2	1,047.7

[a] Calculated from normal carbonates.
[b] Not tested for.
[c] In deposit.
[d] 2.6 in deposit.
[e] 2 in deposit.
[f] .3 in deposit.

TABLE II.—*Water analyses (results stated in salts).*

[Parts in 1,000,000.]

Substance.	I. Artesian well at Lamar.	II. Artesian well at La Junta.	III. Artesian well at Rocky Ford.	IV. Artesian well at Grand Hotel, Pueblo.
Lithium chloride (LiCl)		Trace.	3	108
Potassium chloride (KCl)		12	13	151
Sodium chloride (NaCl)	55	80	32	189
Sodium sulphate (Na_2SO_4)	1,030	1,000	671	393
Magnesium sulphate ($MgSO_4$)	29			1,143
Calcium sulphate ($CaSO_4$)				
Sodium nitrate ($NaNO_3$)			0.5	
Sodium carbonate (Na_2CO_3)		11	67	
Ammonium carbonate ($(NH_4)_2CO_3$)			2	
Magnesium carbonate ($MgCO_3$)	73	72	43	6
Strontium carbonate ($SrCO_3$)			1	
Calcium carbonate ($CaCO_3$)	104	184	37	444
Iron carbonate ($FeCO_3$)		2	6	71
Manganese carbonate ($MnCO_3$)		0.2	Trace.	
Silica (SiO_2)	50	16	12	
Total	1,341	1,377	888	2,505
Sum of $MgSO_4$, $CaSO_4$, $MgCO_3$, and $CaCO_3$	206	256	80	1,593

Substance.	V. Carlile Spring.	VI. Iron Duke Spring. Canyon.	VII. Little Ute Spring, Canyon.	VIII. Underflow well at La Junta.
Lithium chloride (LiCl)				Trace.
Potassium chloride (KCl)	10			12
Sodium chloride (NaCl)	185	1,372	1,956	83
Sodium sulphate (Na_2SO_4)	353	201	207	341
Magnesium sulphate ($MgSO_4$)				179
Calcium sulphate ($CaSO_4$)				250
Sodium nitrate ($NaNO_3$)				
Sodium carbonate (Na_2CO_3)	154	1,267	1,267	
Ammonium carbonate ($(NH_4)_2CO_3$)				
Magnesium carbonate ($MgCO_3$)	195	250	235	
Strontium carbonate ($SrCO_3$)				
Calcium carbonate ($CaCO_3$)	384	535	375	167
Iron carbonate ($FeCO_3$)	5			
Manganese carbonate ($MnCO_3$)				
Silica (SiO_2)				15
Total	1,286	3,625	4,040	1,047
Sum of $MgSO_4$, $CaSO_4$, $MgCO_3$, and $CaCO_3$	579	785	610	596

I. First artesian well drilled by the town of Lamar. Analysis by Dearborn Drug and Chemical Company, Chicago, Ill.

II. First artesian well at La Junta; drilled by the Atchison, Topeka and Santa Fe Railroad Company. Sampled in September, 1895. Analysis by W. F. Hillebrand, United States Geological Survey. When examined by the chemist the water had deposited a slight brown sediment containing iron, manganese, silica, and a trace of phosphoric oxide. This material is included in the analysis. Free and semicombined CO_2, 124.4. Total CO_2, 250.2.

III. First artesian well at Rocky Ford; near Santa Fe Railroad station. Sampled October, 1895. Analysis by W. F. Hillebrand, United States Geological Survey. Reaction faintly alkaline. Specific gravity at 30.5° C., 1.0008. When received by the chemist the water had deposited a sediment containing silica, iron oxide, and traces of alumina (?) and phosphoric oxide. Free and semicombined CO_2, 106.6. Total CO_2, 176.9. Traces of bromides (?), iodides, and phosphates. Organic matter present, but not estimated. No boron, fluorine, or barium.

IV. Trade name, "Colorado Lithia Water." This analysis, by A. Archie Cunningham, appears in a commercial circular, where it is stated in grains per gallon and in hypothetic combinations. It has been recomputed for this table. Trace of phosphates. No organic matter. Another commercial circular gives a somewhat different analysis, without name of analyst.

V. Carlile Spring, north bank of Arkansas River, 18 miles west of Pueblo. Analysis by O. Loew, reported in Explorations West of the One Hundredth Meridian, volume 3, pages 621 and 622. Sample taken in July, 1874. Trace of organic matter. The spring deposits carbonates of lime and magnesia, building a mound.

VI and VII. Iron Duke and Little Ute Springs, near the State prison, Canyon. Analysis by O. Loew, from samples probably taken in 1874. Reported in Explorations West of the One Hundredth Meridian, volume 3, page 617. Water saturated with free carbonic acid. Traces of iron, potassium, and lithium.

VIII. Surface well on the river bank at La Junta. Water drawn from the underflow of the Arkansas River. Analysis by W. F. Hillebrand, United States Geological Survey. Strong reaction for nitrates, but quantity not estimated.

Tables I and II include not only analyses of the water of artesian wells at Lamar, La Junta, Rocky Ford, and Pueblo, but also of the water of a surface well from which the municipal supply of La Junta was pumped (1895), and the waters of three mineral springs which are probably derived from the Dakota sandstone. The Iron Duke and Little Ute springs, of Canyon, rise from the edge of the Dakota sandstone where it stands at a high angle in the hogback skirting the mountain base. The Carlile Spring rises through Benton shales from an unseen source below, and is provisionally referred to the Dakota sandstone, because that is the first water-bearing rock beneath. The well at La Junta is sunk in the flood plain of the Arkansas River and is supplied by the river water, which undergoes no change except a filtration, eliminating the suspended sediment. It doubtless varies in quality with the volume of the river, being purest when the river is high. The sample was collected in September, 1895, with the river somewhat above mean stage.

These analyses come from various sources, and were originally reported in various ways. To make them comparable they have been reduced to uniformity in mode of statement, and in part recomputed. In Table I the constituents are for the most part stated as ions; in Table II, as salts. The second is the more usual form of statement, but the first is of higher authority. Each salt is regarded as composed of two ions. For example: Sodium chloride consists of sodium (Na) and chlorine (Cl); calcium carbonate consists of calcium (Ca) and the carbonic ion (CO_3), a compound of carbon and oxygen. In analyzing a water the chemist determines the presence and proportions of a number of ions, but does not know how they are combined in salts; he is not even sure that they exist in such combination. It is true that when water is evaporated to dryness the remaining solids have the constitution of salts, but the relative amounts of different salts thus obtained vary with the conditions under which evaporation takes place; slow and rapid evaporation, evaporation at high and low temperature, and probably also evaporation at high and low pressure, may give different results. When, therefore, the chemist in reporting the results of analyses states the constituents as salts, the combinations he makes are in great measure hypothetical, and different chemists do not reach the same results. The salts of Table II have all been computed according to the same theory, and are therefore comparable one with another, but it is not assumed that the ions are thus combined in the water. The table attempts only to indicate approximately in what form the mineral contents of the water will appear (regardless of water of crystallization) if separated by evaporation at ordinary temperatures and pressures.

In the arrangement of these tables and in the discussions of the data they present, I have availed myself of the expert knowledge and friendly aid of my colleagues in the chemical division of the Geological Survey, especially Prof. F. W. Clarke and Dr. W. F. Hillebrand.

The analyses show that the mineral contents of the Dakota waters include sulphates, carbonates, and chlorides, the sulphates being much the more abundant. The principal metals are sodium, calcium, magnesium, and potassium, their abundance being usually in the order named; silicon and lithium are present in small amount. Of salts, sodium sulphate is most abundant in the wells at Lamar, La Junta, and Rocky Ford; magnesium sulphate and calcium carbonate in the Grand Hotel well, Pueblo; sodium sulphate and calcium carbonate in Carlile Spring; and sodium carbonate and sodium chloride (common salt) in the Canyon springs.

No attempt will be made to set forth the full bearing of these facts on the utilization of the waters, but a few salient points may be noted. The total mineral content is so large as to produce an appreciable and ultimately deleterious deposit in irrigated soil, unless occasionally leached out or neutralized by corrective dressing. The waters of the three springs and of the Grand Hotel well, containing from one-fourth to one-third of 1 per cent of solids in solution, are less desirable than the others for general use as drinking water, but they should nevertheless be preferred to the ground water and river water of the country, which are easily contaminated by organic poisons. For other domestic uses, and especially washing, the purer waters are in general best, but the various impurities are not equally obnoxious. In a general way, the hardness of water, or its intractability with soap, corresponds to the quantity of its carbonates and sulphates of calcium and magnesium, and judged in this way the Rocky Ford water is best and the Grand Hotel poorest of the series analyzed. For convenience of comparison the sums of these carbonates and sulphates are placed at the bottom of Table II; they constitute an approximate scale of "hardness."

The same scale also serves to show the comparative tendency of the waters to form deposits in boilers, as these salts either separate as such when the water is reduced by boiling or are decomposed and separated in other forms. The water supplied to locomotives of the Atchison, Topeka and Santa Fe Railroad at La Junta was for a number of years drawn from a shallow well near the river (Analysis VIII), and much trouble and expense were occasioned by the rapid formation of boiler scale. In 1895 the water of La Junta artesian well No. 1 (Analysis II) was substituted, with strikingly beneficial results, the cost of cleaning and repairing boilers being reduced more than one-half. Dr. Hillebrand, who analyzed both waters, writes of their comparative value for engine use as follows:

> The mineral constituents of waters most concerned in the formation of boiler incrustations and deposits are certain salts of calcium and magnesium, chiefly the carbonates and sulphates, and in case of magnesium the chloride also. From the "hypothetical combination" column of the surface waters [VIII, Table II] it appears that there are nearly 600 parts per million of calcium and magnesium compounds available for the formation of scale, while in the artesian water [II, Table II] there are at most but 256 parts per million thus available, or less than one-half. For this reason the artesian water should be less troublesome in boilers than the surface waters, and such I understand from you is the case.

Judged by the same criteria, the Lamar artesian water (Analysis I) is of equal value for boiler use with the La Junta, and the Rocky Ford artesian water (Analysis III) is much better than either.

As to the medicinal properties of the Dakota waters, I have not attempted to inform myself. The waters of Carlile Spring and the Grand Hotel well are advertised and sold as therapeutic, and the waters of the Grand Duke and Little Ute springs have given Canyon some reputation as a health resort.

PREDICTION.

The cost of making an artesian well depends largely on the thickness of rock which must be penetrated in order to reach the water. A knowledge of this depth is therefore important to anyone who contemplates drilling. It is also important to know whether the water of a well drilled at a given point may be expected to flow out at the surface or only to rise to some level below the surface. Prediction as to these two points will doubtless have greatest value if made by a geologist who has personally studied the district, but in many cases the resident can be his own geologist, and it is worth while to point out how he can help himself to the knowledge he desires.

The general arrangement of the rocks is shown in the sections of Pl. LXVIII, and some general facts as to the depth of artesian water are embodied in fig. 49; but there are many important details of which these diagrams take no account, and it is also true that the geologic work on which they are based was not sufficiently thorough to give full warrant even to the lines which have been drawn. Another part of the work, however—the determination of the sequence and thickness of the rocks—was performed in a more satisfactory manner, and its results, when properly applied by the seeker for artesian water, may aid him in making a useful estimate of the cost of obtaining it. In the description of the Cretaceous formations, in the earlier sections of this report, care was taken to give prominence to such special features as may serve to distinguish particular rocks wherever they are found at the surface. Their general characters—as sandstone, shale, limestone—were given, the special modes in which the two principal limestones break up at the surface were described, pictures were given of the fossil shells most likely to be found in each of the limestones and also in certain shales; small nodules contained in one of the limestones were pictured, and a type of hill produced by the presence of hard masses in one of the shales was figured. If by the aid of these characters the inquirer can determine the particular formation which exists at the surface at any point, he can then, by the aid of fig. 46, tell how deep it will be necessary to drill in order to reach the first water-bearing sandstone.

Often there are no good exposures of rock at the place where a well is desired, and the nearest outcrop of recognized rock is so far away as to leave the geologic relations of the locality in doubt. In such cases it is well to be able to recognize different formations as the drill descends. For this purpose it is advantageous to compare the material brought up by the sand pump with samples of the drillings obtained at various depths from some other well of the district, and by means of such comparison it will often be possible to make a close estimate of the remaining distance to the water-bearing rock. When such comparison can not be made, there is still one bed which can always be recognized, provided the work is begun at some level above it, and that is the limestone at the base of the Timpas formation. Its fragments are almost white, and are thereby distinguished from nearly all other rocks of the district. The thickness of the bed, from 35 to 50 feet, is much greater than that of any other limestone of the district. To determine that the chips are actually of limestone a few of them should be placed in a glass of dilute hydrochloric (muriatic) acid. The acid attacks the limestone, changing it to chlorides of calcium and magnesium, which are dissolved, and setting free carbonic acid gas, which escapes in bubbles. When the bubbling has ceased it will be found that the limestone chips have completely disappeared, leaving the liquid clear or very slightly cloudy. If flakes of shale are put into the acid, there is usually some effervescence, because most of the shales of the district contain a small amount of calcium and magnesium carbonates; but after the effervescence has ceased it will be found either that the flakes retain their original form and size or else that they have been broken up into minute particles, so as to make the liquid muddy. Such a test will be useful in case there is doubt as to whether the limestone has been reached. The distance from the bottom of this limestone to the first water horizon is about 450 feet.

The question whether the water when reached will rise higher than the surface, or not so high, is a question of head. As the water lies in the sandstone before it is tapped it presses against the overlying formation, and that pressure is measurable, like the pressure of steam, in pounds per square inch. For every pound of pressure the water is able to rise 2.3 feet above the top of the water-bearing stratum. If the overlying rocks be pierced and a tube fitted to the opening and carried indefinitely upward, then the water will rise in this tube to a height corresponding to the pressure exerted at the base. At every height the water will press on the tube, but the amount of such pressure will gradually diminish upward, so that at the top of the water column the pressure will be nil. A drilled well from which water naturally flows may be compared to such a tube as has been described. If it be continued by a pipe above the ground, the head can be determined by finding how high the water rises; but in case it is not practicable to do this the same result may be accomplished by cutting off the flow of the well and attaching a pressure gage; then for each pound of pressure shown by the gage 2.3 feet must be added to the height of the position of the gage in order to compute the height of the head. The ordinary steam gage, if new, is sufficiently accurate for this purpose. It will usually be found that after the flow of a well is stopped the pressure increases somewhat rapidly at first, and then more slowly. By watching the gage from hour to hour it will be seen that the increase of pressure finally becomes inappreciable, and the reading may then be taken.

For various reasons the pressure of artesian water on the walls of its reservoir varies from point to point, and the absolute height to which the Dakota water will rise is not everywhere the same. If for each point of the reservoir a point were marked somewhere above indicating the head of the water, then these latter points would together constitute a surface sloping in various directions. In some places this imaginary surface would stretch above the surface of the soil, and there flowing wells might be obtained; elsewhere it would pass through the rocks beneath the soil, and there only pumping wells might be secured. Of the actual slopes of such a surface little is known as yet, and for practical purposes it is at present best to assume that within any limited district, such as might be called a neighborhood, the surface is horizontal. On this assumption the head determined for an existing well shows the head which may be expected for a new well in the same neighborhood. If the water in an existing well does not rise to the surface, but stands at a certain distance below, then it is evident that one must go down hill in order to find a place where a flowing well can be made. If the existing well furnishes water freely at the surface, then by measuring its head one can determine how far up hill a well can be located without losing the probability of a surface discharge.

Where there are several water-bearing rocks within reach of the drill, each water sheet will ordinarily have a different head from the others, and under ordinary circumstances the head of the lowest sheet will be the greatest. Information as to the several pressures exerted by water from different strata is therefore of importance to the community.

GROUND WATER.

The arrangement of strata necessary to the retention of water under pressure is comparatively rare, so that artesian water is the exception rather than the rule; but the conditions favorable to the accumulation of ground water are widespread. The bed rock of a country is usually overlain by a deposit of loose material, such as loam, sand, or gravel. So much of the water of rain as escapes evaporation and does not immediately run away over the surface sinks into this loose material and finds its way gradually downward until it meets with some impervious formation. Its downward course is then checked, and it either remains stagnant, as a sort of subterranean lake, or flows slowly in some direction, as a sort of subterranean stream.

GENERAL CONDITIONS.

The quantity of ground water in the ground, its depth beneath the surface, its quality, and the direction and rate of its flow depend on a variety of circumstances. The supply is necessarily limited by the rainfall, but is usually far less in amount, because a portion of the falling rain runs away and another portion is evaporated directly from the surface of the soil. A very porous soil captures more of the rain than can be received by a soil of fine texture, and it has the further advantage that it permits so free a flow that much of the water descends quickly to the reservoir beneath, whereas a less pervious soil tends not only to hold the water near the surface, but to return it to the surface as evaporation progresses. Where the layer of loose material is shallow the circulation of dry air through it may carry away ground water, but where it is deep such loss is practically prevented.

Digging down through the surface layer of earth, one may often find it dry or moist or alternately dry and moist, and if these characters continue until impervious rock is reached, there is said to be no ground water—that is to say, there is no water which will accumulate in a well. Often, however, the lower part of the layer is not merely moist, but is filled with water, and wherever it is thus saturated the water will flow from it, filling the lower part of the excavation. The surface separating saturated earth from earth that is merely moist is the upper limit of the ground water, and marks everywhere the height at which water will stand in a well. It is called the "water table," or, more appropriately, the "water plain." It is usually not a level surface, but slopes in various ways, and the direction of its slope is always the direction in which the ground water flows. In some localities the water plain may be parallel to the surface of impervious rock beneath; in other localities it may be parallel to the surface of the ground; but usually it is an independent surface, following its own laws of slope.

The rate of movement of ground water is very slow as compared to the flow of a surface stream. Its slowness depends on the great friction produced by the movement of water through narrow passages. Sand permits more rapid currents than fine earth, and the currents through clean gravel are much more rapid than through sand. The coarser formations are thus not only more receptive of water, but transmit it more quickly and part with it more easily.

The quality of ground water varies greatly from place to place. Where the supply is large and the flow comparatively rapid, the more soluble mineral constituents of the soil are soon leached out, and the water afterwards carries only a small amount of the less soluble materials. Where the supply is small or the water nearly stagnant, it may contain a large amount of the more soluble salts. Ground waters usually contain a notable quantity of organic matter—material derived from the decomposition of animal and vegetable tissues—and with these are associated microscopic organisms. Such ground waters as are replenished from the soil directly above them by the water of every storm are peculiarly susceptible to such contamination.

WATER OF THE UPLAND SANDS.

In the district under consideration the most important reservoir of ground water is the group of deposits already described as the upland sands. At most points wells sunk through these sands find water before reaching the bed rock, and the presence of the water is otherwise demonstrated by the springs occurring at the margins of the formation. Little is known as to the quantity of water contained in the sands. The wells afford little information, because the digging is usually stopped soon after the water plain is reached; and only a small portion of the evidence they are capable of affording was gathered during my work. In some places the wells show that the ground water is a very thin sheet, and in others that it is altogether absent.

Some of the wells pass through a great depth of fine earth that seems entirely dry, and in such localities it may be doubted whether any of the rain water ever finds its way to the base of the formation. Elsewhere the greater part of the formation is moist to the top. It seems, therefore, probable that the ground water is not replenished by the rains of the whole district covered by the upland sands, but only in those tracts where the upper part of the formation has a somewhat open texture; but no progress has been made in determining the extent and position of such areas of supply. The principal body of upland sands extends northward and northwestward beyond the region of observation, and as the country rises in that direction search for the sources of supply would naturally be directed that way. There is a popular impression in some parts of Kansas that the water enters the formation on the slopes of the Rocky Mountains, where the rainfall is great, but there is good reason to regard this view as erroneous. There is probably no place where the formation extends so far west as the flanks of the mountains.

A long line of springs marks the southern edge of the northern area. Among them may be mentioned the Nusbaum Spring, a few miles northeast of Pueblo; a group of springs in the banks of Chico and Black Squirrel creeks near their junction; Antelope Spring, at the head of Bob Creek Valley, and the great spring near Coolidge, Kans. Horse Creek, Adobe Creek, Rush Creek, and Big Sandy Creek probably derive their chief supply from the same source. None of these streams are so large as to carry water at the surface the whole year, but there is always a considerable body of underflow beneath their sandy beds. South of the Arkansas the upland sands nourish the springs at the head of Clay Creek, and sustain Two Butte Creek, which, like the more northerly creeks, carries most of its water in the sands of its bed. It is reported of these springs that they are uniform in flow from season to season and from year to year. This character indicates that the principal supply in each case comes from a considerable distance, or, what amounts to the same thing, that it is derived from a large tract of country. The volume of the creeks is much more variable, doubtless because it depends in part on that portion of the rain water which flows down the surface of the slopes. No analyses have been made of these waters, but they differ from the artesian waters in that they have no notable taste. Their behavior with soap indicates that they are in general somewhat charged with the less soluble salts.

The water obtained by wells shows greater variety than the spring water, and some of it is both unpalatable and unwholesome. The differences doubtless depend somewhat on the character of the underlying rock, but are probably more closely related to the volume of flow. Where the flow is comparatively rapid the chlorides and more soluble sulphates have already been leached out; but where the currents are feeble the leaching is still in progress. Only the stronger streams give rise to springs, and the spring waters are therefore comparatively pure. Wells may draw their supply from the underground currents which end in springs, and thus obtain water of the same quality, or they may reach only the comparatively stagnant portions of the underground sheet.

WATER OF THE TERRACES.

There may be some instances in which the sands of the Arkansas terraces, resting against the slopes of the Dakota sandstone, receive water from that formation; but in general their supply comes only from the rain on their surfaces, and the gathering ground is too small to create a free circulation. I am not acquainted with any springs which issued from such terrace formations before the institution of irrigation, and many wells sunk in the terraces are unsuccessful. The lower terraces are, however, much used for irrigation, as they afford gently sloping bodies of land to which the river water can be carried by canals of moderate length. When they are irrigated, the sands and gravels which cap them gradually imbibe the water of irrigation and eventually become well charged with it. The water plain usually rises to within a few feet of the surface, and springs abound along the bluffs that margin the terraces. Some of the wells afford fresh water; others, water that is notably saline or alkaline; and individual wells often change their character as the development of irrigation progresses. The marginal springs are usually of poor quality and are often highly charged with the more soluble salts. It seems evident that the circulation thus artificially introduced is leaching soluble material not only from the sands and gravels which cap the terraces, but also from the upper part of the underlying shales, and many years must elapse before this process will have advanced so far that the water of the marginal springs is palatable.

WATER OF THE DUNE SANDS.

The regions of wind-blown sand are better adapted than most parts of the district to the reception and storage of rain water. Not only is the surface soil of such open texture as to absorb the whole of the gently falling rain, but the surface undulates in such a way as to inclose numerous basins in which the water of the more violent storms is impounded until it can soak into the ground. Nevertheless, the presence of ground water has rarely been demonstrated in such districts, because the deeply porous soil unfits it for irrigation, and its natural vegetation is of a character affording but lean pasturage. The dune tracts are therefore mainly uninhabited, and the underlying water is not utilized.

UNDERFLOW OF RIVERS AND CREEKS.

All of the larger streams of the district flow through bottom lands of loam, sand, and gravel. These bottom lands are composed of materials which have been transported and deposited by the streams themselves. The action of streams, as already explained, deposits comparatively coarse material at bottom and comparatively fine material at top, so that beneath the bottom lands there are usually porous beds, such as coarse sand or gravel. Sometimes these coarse beds extend no deeper than the bottom of the stream channel, but more often they are of greater depth. In either case they constitute a reservoir for water. Where the surface flow of a stream is not continuous, but depends on occasional storms, a part of the storm water is received by the stream sands and is thus stored. It also flows slowly through the sand in the direction of the descent of the valley. The stream sands may thus be regarded from one point of view as reservoirs, and from another as the channels of underground streams.

That the water actually flows is shown by the condition of the larger creeks and smaller rivers during dry seasons. Where the bottom land or flood plain is broad no water is seen at the surface; but where it is narrowly hemmed in by canyon walls the bottom of the channel may be occupied by a running stream. The water which thus at points of constriction appears at the surface may be seen to issue from the sands of the valley above the constriction and to disappear again in the sands below. It is evidently part of an underground stream brought locally to the surface by the narrowing of its channel. The quantity of flowing water thus revealed is always very small as compared to the capacity of the superficial stream channel, and it is also small as compared to the capacity of the sand bed or subterranean channel above and below the point of constriction.

The underflow of the Arkansas River is rarely demonstrated by the phenomena of disappearance and reappearance, but there can be no doubt that it is greater than that of any tributary. The body of sand is in general broad, it is usually somewhat deeper than the surface water channel, and it is so coarse as to imbibe water freely. Regarded as a reservoir, it is unquestionably of great importance, and its water may also prove valuable as a flowing stream.

Considered as a reservoir, the Arkansas sands have a breadth approximately as great as the bottom lands and a depth ranging from 5 to 20 or 30 feet. They are in general charged to a level somewhat above the low-water surface of the stream. In time of flood there must be a lateral flow from the stream channel into the sands, and in time of drought a movement in the opposite direction. Where irrigation is practiced, the river sands also receive some of the seepage from the fields, and their water plain is thereby raised.

In connection with the present work no attempt has been made to estimate the volume of available water contained in this reservoir. Such a computation would require not only the measurement of the area and depth of the saturated sands, but a comprehensive knowledge of their ability to absorb and deliver water. Very little observation is necessary to show that the sands are exceedingly variable in texture, and an estimate which failed to take account of this variability might easily go far astray. In order to obtain some general idea of the quality of the river sand in this respect, Mr. Newell collected two samples from the river-bed at Lamar, the one representing the coarser and the other the finer of the sands there exposed. The coarser sample was afterwards tested by Mr. G. W. Stose, in the following manner: After being thoroughly dried it was saturated with water, and the quantity of water received was determined by weighing. The vessel containing it was then punctured at the bottom, so as to permit the water to drain away, and after a lapse of several days the loss of water was determined by another weighing. It was then found that the sand had received 29 per cent of its volume of water, but afterwards parted with only one-third of the water received, equivalent to 10 per cent of the whole volume of sand.

The conditions under which the experiment was tried represent fairly well the ordinary conditions under which water is drawn by wells from the river sands, and if there was good reason to believe that the sample was properly representative of the river sands in general, we might conclude that each cubic foot of saturated sand along the river contains, on the average, one-tenth of a cubic foot of available water. A sample of sand taken from one of the ancient deposits of the Arkansas River, now exposed in the face of "the Mesa," near Santa Fe avenue in Pueblo, was similarly treated, being found to absorb 29 per cent of water and deliver only 3 per cent. A sample from the bed of Big Sandy Creek, near Water Valley, gave a much better result, absorbing 30 per cent of water and returning 21 per cent.

It is even more difficult to obtain a just estimate of the volume of the river-sand water considered as a stream. The speed with which ground water flows depends on the relation of the impelling force to the resistance. The force is measured by the slope of the water plain, and that, in the case of the Arkansas River, is from 7 to 15 feet per mile. The resistance varies in some complex way with the texture of the sand; it also varies with the rate of flow, but not in a simple arithmetical way. A thorough treatment of the subject would therefore require a knowledge of the law under which the velocity of water is determined by the impelling force and of the texture of the sand, and also a local knowledge of the variations of sand texture in different parts of the section. It is to be hoped that both these subjects of inquiry will soon be taken up by the division of the Survey specially charged with the investigation of water supply, but at the present time there is no evidence on which to base a definite judgment. In any case the volume of water flowing through any given cross section in a unit of time must be very much smaller than the average discharge of the surface stream.

The underground water of the stream beds is almost as variable in quality as that of the upland sands, and, except for suspended and visible impurity, is quite as variable as the overground water of the streams. In general the water of the longer streams is purer near its source than after it has flowed for a great distance and been reduced by evaporation. Where irrigation is practiced, there is still further deterioration by reason of the mineral matter brought from the irrigated soils and subsoils. The saline and bitter waters which issue from the springs along the margins of the irrigated terraces are perpetually contaminating the river waters, both above ground and below, and along the lower reaches of the river it must be expected that the quality of the underflow will for many years steadily deteriorate. Changes of this sort have been reported by some of the older residents, but determinations depending on taste and other matters of ordinary personal observation are subject to considerable question. A more authoritative observation is that made by the officers of the Santa Fe Railroad at La Junta, where the difficulties occasioned by the deposit of mineral impurities in boilers are reported to have steadily increased for years, until the growing expense occasioned by them led to the search for a better water supply by means of the drill.

ACKNOWLEDGMENTS.

My indebtedness to various individuals and publications for assistance and information has been acknowledged on the preceding pages, but there are certain obligations which could not be conveniently or adequately recognized in such way. In the preparation of the manuscript I have frequently conferred with my colleague, Mr. F. H. Newell, and have drawn freely on his expert knowledge of the general subject of water supply. The names of fossils are given on the authority of Mr. T. W. Stanton, and he has kindly assisted me in the selection of specimens to be figured in the preparation of some of the illustrations. In addition to the gentlemen whose names are mentioned in the report, I have been materially assisted in my search for information as to artesian wells by Mr. C. H. Small, of Pueblo; Hon. G. W. Swink, of Rocky Ford; Mr. W. W. Jones, of Granada; and Mr. A. D. Jones, of Coolidge.

PRELIMINARY REPORT ON ARTESIAN WATERS OF A PORTION OF THE DAKOTAS.

BY

NELSON HORATIO DARTON.

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PRELIMINARY REPORT ON ARTESIAN WATERS OF A PORTION OF THE DAKOTAS.

By N. H. Darton.

INTRODUCTION.

The great artesian basin of the eastern portion of South Dakota and North Dakota has been so extensively developed by wells in the past decade that its general features are now well known. There is, however, great demand for detailed information as to the location of the water-bearing beds, the limits of the territory in which artesian flows may be expected, and the prospects for a continued water supply. There is also need for a statement of the extent and progress of well sinking and an account of the results of irrigation by the waters. In the autumn of 1895 I was directed to make a study of these questions, and this report gives the results of the preliminary investigations.

In Pl. LXIX are indicated the locations and depths of the deeper wells in the region studied, and also the area of artesian flow. On March 1, 1896, I estimated from all available data that the total number of the deeper artesian wells is about 400, of which over 350 are now flowing satisfactorily. The aggregate flow, as nearly as can be estimated, is 104,000 gallons per minute—232 cubic feet per second—or a little over 150,000,000 gallons per day. Eighty per cent of this flow is from 68 wells; of these, 31 have a flow of from 500 to 950 gallons per minute; 27 have a flow of from 1,000 to 1,950 gallons per minute, and 6 wells have a flow of from 2,000 to 2,900 gallons per minute. A well at Chamberlain is reported to have a flow of 4,350 gallons per minute; one at Springfield flows 3,292 gallons per minute; one at Yankton 3,000 gallons per minute; one on the Green farm in Brule County 3,000 gallons per minute; and one on the Yankton agency 3,000 gallons per minute. Much of this flow is shut off part of the time, but the figures indicate the present resources in artesian waters. These waters rise to the surface with pressures which are often over 100 pounds per square inch, and in a few cases over 150 pounds. At a number of localities this pressure is directly used for power to run large flouring mills, electric-light plants, sewage pumps, and other machinery. The principal use of the water is, however, for irrigation, and the greater number of the larger wells have been sunk for this purpose.

THE NATURE OF THE INFORMATION.

In the preparation of this report I have endeavored to utilize all available data, including a considerable amount derived from other observers. The report by Col. E. S. Nettleton to the Department of Agriculture[1] has been the source of a larger part of the information concerning wells sunk prior to 1890 in the James River basin. In this report are given descriptive notes of all the deeper wells, a brief description of the conditions under which the waters occur, and vertical sections showing the relation of wells along a number of lines. The report also includes chapters by Prof. G. E. Culver and Maj. Fred. F. V. Coffin, which furnish important data.

Prof. J. E. Todd, State geologist of South Dakota, has presented some new "logs" and other information regarding wells in his Geology of South Dakota, which I have been glad to use. Information has also been derived from the report of Capt. C. S. Fassett, State engineer of irrigation, for 1893–94, and from the report of Mr. W. W. Barrett, State superintendent of irrigation and forestry in North Dakota.

From the 15th of September to the end of November, I had the assistance of Maj. Fred F. V. Coffin, who thoroughly canvassed large areas of the southeastern corner of South Dakota and obtained much valuable information, consisting of descriptions of wells, "logs," irrigation results, and data regarding the shallow waters. My own observations covered nearly all portions of South Dakota east of the Missouri River, the lower James River valleys of North Dakota, a trip into the Rosebud Indian Reservation, and a study of the geology from along the eastern slope of the Black Hills to the Cheyenne Valley. I had personal interviews with a number of well owners and well drillers, and a very large amount of information was obtained by means of blank schedules sent all over the artesian-well regions.

Considerable difficulty has been experienced in obtaining reliable information in regard to well borings and experience. For many of the wells no records could be obtained, and in some cases it was difficult or impossible to ascertain even depth and yield. The interpretation of well records supplied by various persons is always a difficult and uncertain task for the geologist, since many of the well drillers use haphazard terms of description for the materials which they penetrate in boring wells and trust much to memory when writing their "logs."

OUTLINE OF GEOLOGIC RELATIONS.

The geologic features of North Dakota and South Dakota are relatively simple, and they are mainly uniform over very wide areas. From the descriptions by Professor Todd and others we can obtain a

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[1] Artesian and Underflow Investigation, Final Report of the Chief Engineer, Edward S. Nettleton, C. E., to the Secretary of Agriculture, with accompanying maps, profiles, diagrams, and additional papers; Part 2, 116 pages, 27 plates, Fifty-second Congress, first session, Senate Ex. Doc. 41, Part 2, Washington, 1892.

MAP OF ARTESIAN BASIN IN EASTERN S. DAKOTA AND A PORTION OF N. DAKOTA. BY N. H. DARTON

Scale: 0 5 10 15 20 25 50 miles

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clear insight into the general relations, and as it is necessary to understand these relations in considering the conditions of underground water supply, a brief description of the geology is desirable. East of the vicinity of the Missouri River the surface is occupied to a greater or less thickness by gravel, clays, and sands, which were deposited by or in connection with the great continental glaciers of the Glacial period. These formations vary in thickness from 40 or 50 feet to over 100 feet, and they are so continuously spread over the surface that exposures of underlying formations are relatively few, particularly to the east and northeast. Lying beneath the drift and occupying the surface over the plains region westward in South Dakota are clays or shales of the Cretaceous period. Their thickness averages 1,000 feet over the greater part of the area, but they thin rapidly east of James River. In the region adjoining White River and extending thence southward through Nebraska this clay formation is overlain by a much younger series of Tertiary clays and sandy clays which occupy the surface in the Rosebud and Pine Ridge Indian reservations and in the Bad Lands. They have a thickness of between 300 and 400 feet in their greatest development. North of the Cheyenne River, and extending thence far to the north and eastward into North Dakota, the Cretaceous clays are overlain by sands and sandstones known as the Laramie formation.

FIG. 50.—Vertical section from eastern portion of the Black Hills across South Dakota, showing the attitude and relations of the water-bearing Dakota sandstones; looking north; 300 miles long; vertical scale considerably exaggerated.

In the southern portion of South Dakota the Cretaceous clay series includes an extensive deposit of calcareous material about 300 feet above its base, which is known as the Niobrara chalk. This chalk formation outcrops extensively along the Missouri Valley below Chamberlain. The underlying beds are known as the Benton clays, and the overlying beds as the Pierre clays or shales.

Beneath the Cretaceous clay series lies a relatively thin but widely extended sheet of sands and sandstones, containing thin, irregular, intercalated beds of clays and iron pyrites. It is known as the Dakota formation, and it has proved to be a great water-bearer over wide areas in both States. To the southeastward it lies upon, or perhaps merges into, a pink quartzite, which attains great thickness in the vicinity of Sioux Falls. Adjacent to this area of quartzite the Dakota formation rises to the surface or lies under the drift at no great distance below, but to the north and west it is deeply buried below the great mass of Cretaceous clays, in addition to which, in the region south of the Cheyenne River, there is the overlying series of Tertiary clays, and to the north of that river the overlying Laramie sands and sandstones. In the Black Hills it is brought abruptly to the surface by an uplift in which the crust of the earth is sharply domed over an area of several thousand square miles. This doming or uplift also brings to the surface the formations underlying the Dakota formations, which are here seen to be a thick mass of sands, limestones, sandstones, granites, and schists. These limestones and sandstones are also known to underlie the Dakota formation in the eastern part of Nebraska and northward in Canada, but they appear not to extend far eastward across the Dakotas, where, over a wide area, the Dakota sandstone appears to lie directly on granite or quartzite. The granites and schists are the "bed rocks" of the entire region and extend to an indefinite thickness.

The geological structure of South Dakota from the Black Hills eastward is shown in the cross section, fig. 50. In this section are indicated nearly all the features above described excepting the Laramie formation, which lies north of the line of section and appears to thin out to the southward, so as to be absent from between the Tertiary clays of the White River region and the great Cretaceous clays series. Some of its relations in North Dakota are shown in fig. 59.

THE WATER HORIZONS.

The principal water-bearing bed in the Dakotas appears to be the eastward extension of the Dakota sandstones, but water is also found in smaller amounts in the Niobrara chalk beds above, in the basal beds of the drift formations, and in local beds of sand in the great series of clays lying above the Dakota formation. The Dakota formation consists of sands and sandstones which are particularly favorable in their character for the storage and transmission of water. The formation is not entirely sand and sandstone, but contains beds of clay irregularly disposed, and often streaks of iron pyrites and iron stone. The texture of its sands and sandstones being variable, the capacity for holding water is by no means constant. In every well of which I have heard that has penetrated the Dakota formation some water has been found in one bed, if not in others, and often several horizons of water-bearing sands have been penetrated. In many of the wells two or three, and

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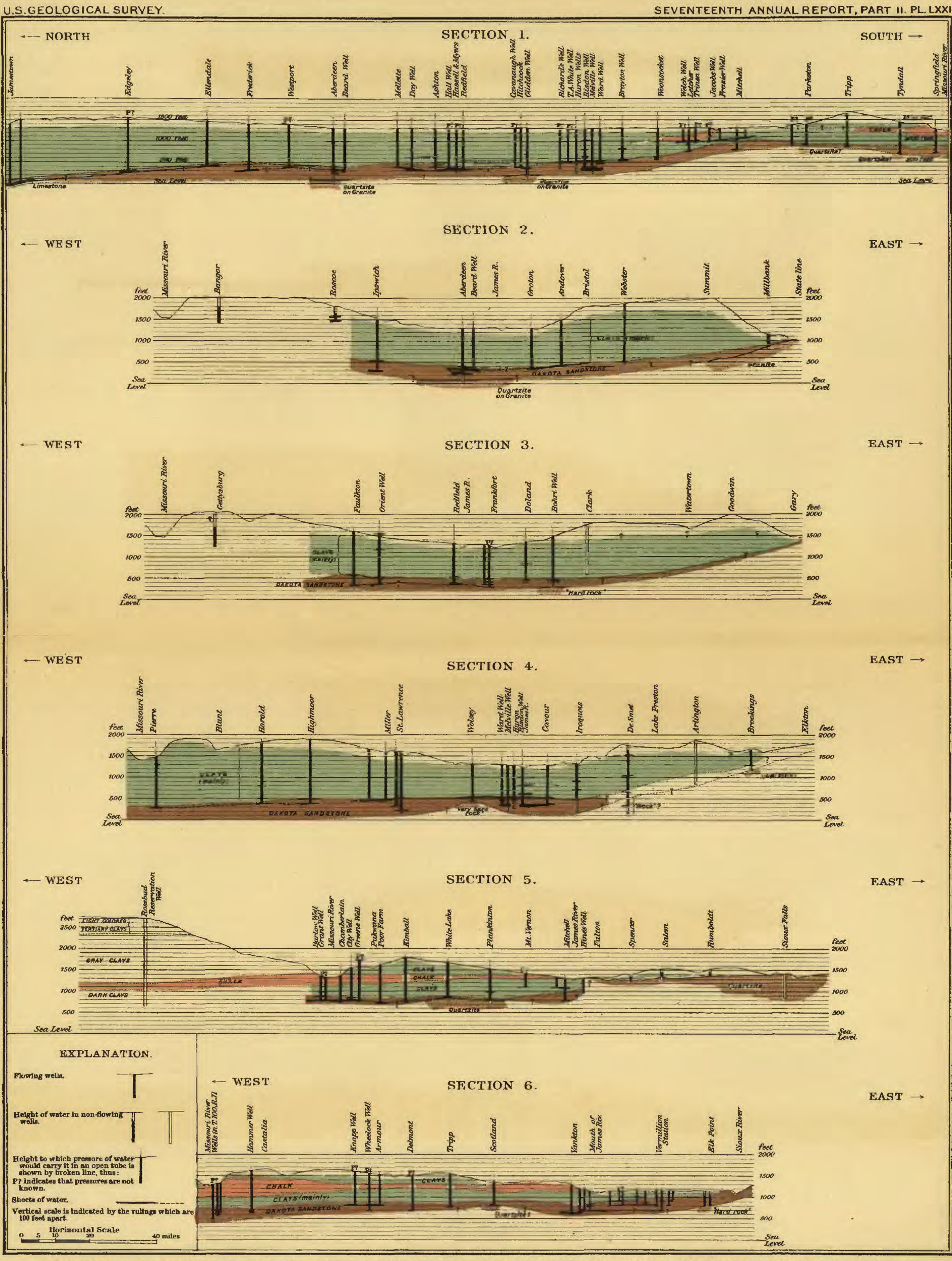
HYPSOMETRIC MAP OF A PORTION OF SOUTH DAKOTA AND NORTH DAKOTA. By N. H. DARTON.

ALSO SHOWING BY NUMBERS IN BLUE THE FEET ABOVE SEA-LEVEL TO WHICH THE ARTESIAN WATERS WILL RISE, AS CALCULATED FROM THE PRESSURES IN WELLS.

SCALE: 0 5 10 15 20 25 50 MILES



VERTICAL SECTIONS THROUGH THE ARTESIAN BASIN IN THE EASTERN PORTION OF THE DAKOTAS

BY N. H. DARTON

JULIUS BIEN & CO. N.Y.

in some as many as seven flows have been found, separated either by clays, beds of pyrites, or more compact sands or sand rock. In a few instances borings have penetrated sands whose physical characteristics appear to be favorable to a flow of water, but none has been found. In these cases it is probable that the nonwater-bearing bed was completely inclosed in clays or other impervious materials. In such instances water has been obtained by penetrating to lower beds to which the water has free access. It is by no means certain that the lowest beds in the artesian basin all belong to the Dakota formation, for they may be attenuated representatives of formations which in the Black Hills, Rocky Mountains, and Mississippi Valley lie between the Dakota beds and the crystalline rocks. None of the wells have, however, furnished definite evidence as to the age of the formations beneath the Dakota beds. Doubtless over wide areas the Dakota sandstones rest directly on the crystalline rock surface.

In an area of about 600 square miles lying mainly in eastern Sanborn and western Miner counties fairly abundant supplies of excellent water are obtained from wells in the chalk deposits. The flows have no great pressure, but the head is sufficient to carry the water over the more level farms, and the wells have proved to be very serviceable. Their depths average from 100 to about 350 feet. In some cases the water occurs near the top of the chalk, in others at various horizons below. A few wells derive their supply from sands lying entirely below the chalk.

Small artesian flows are obtained from the drift deposits in portions of Sanborn, Miner, and Hanson counties, in an area of which the outlines are indicated in Pl. LXIX. There is another small area along the valley of Turkey Ridge Creek, in Turner County, and there are a few scattered wells in lowlands at various points in other counties, as shown on Pl. LXIX. These wells have an average depth of about 100 feet, but some are not that deep and a few are much deeper. They derive their waters from the coarse sands and gravels which lie under the blue clay at the base of the drift deposits, but it is possible that this water is furnished originally by the chalk, which either immediately underlies these coarse beds or is separated from them by a short interval of more or less permeable beds.

There are many local occurrences of waters at various horizons in the clay formations that overlie the Dakota sands and sandstones. In some cases they are in sands intercalated in the clays lying between the chalk and the Dakota beds, and in others they lie at greater or less distances above the chalk. At Mandan, in North Dakota, the small flow of water in the 2,000-foot well is obtained from beds at a depth of about 350 feet, which are high up in the Pierre clays. Nearly all the wells have reported small flows in sands or sandy shales at horizons considerably above the Dakota formation, but I have been unable to ascertain whether they represent definite horizons. In many cases they furnish such a scanty supply that they are worthy of no consideration, but over quite a wide area north of Mitchell there are a number of wells with large flows and fairly high pressures which obtain their supply from sands in clays above the main Dakota horizon.

THE EXTENT OF THE ARTESIAN WATERS.

Almost the entire area of the States of North Dakota and South Dakota is underlain by the Dakota sandstone, and this formation appears throughout its extent to be more or less completely saturated with water. From its outcrops in the Black Hills it sinks deeply beneath the surface, and then gradually rises to the eastward, as shown in fig. 50. It finally abuts against the crystalline bed rock along the eastern border of the States at no great distance beneath the surface, where its waters are more or less free to escape and the eastern limit of the basin is determined. The waters have a head which is relatively great to the westward, but gradually diminishes to nothing at the eastern border of the basin. There are wide areas in which this head is sufficient to give surface flows in artesian wells, but, on the other hand, there are many thousand square miles which are too elevated for artesian flows. These elevated regions comprise the greater part of the highlands of the plains country west of the Missouri, the western Coteau north of latitude 44° 45′ north, and the eastern Coteau in South Dakota. On Pl. LXIX is shown the area in which artesian flows may be expected, both from the Dakota sandstone horizon and from certain higher horizons of local extent.

The restriction of the artesian area on the eastward is quite definitely proved by the experience of a number of wells which have been bored along the eastern Coteau. These wells are at Webster, Clark, De Smet, Brookings, Madison, Salem, and Bridgewater, and along the Big Sioux Valley. In some of these wells, as will be described more in detail in the following pages, waters have been found in fairly large supplies, and probably in the Dakota horizon, but they have not had sufficient head to rise to the surface as artesian flows. In the case of some of the wells, the head was sufficient to raise the water to altitudes considerably above the level of the wells in the lowlands westward, but they fall far short of the surface of the highlands into which they were bored.

The failure of the well at Millbank, in the Minnesota Valley, northeast of the eastern Coteau, to obtain a flow is due to the diminished head of the waters to the eastward, and it falls in line with the results at Brookings and in the Sioux Falls Valley. Various borings have been made at a number of localities within the known artesian area which have failed to find water, but it is now quite clearly apparent that they were not sunk sufficiently deep to reach the horizon in which waters are to be expected. For instance, at Fort Sully a 979-foot well was discontinued in the clays fully 200 feet above the water horizon, and the 600-foot boring at Bangor, at an altitude of about 2,000 feet, was abandoned still farther above the Dakota formation. The 2,000-foot boring at Mandan, N. Dak., probably did not reach the Dakota formation, and the boring at Bismarck was not sufficiently deep by about 1,000 feet.

The waters of the shallow artesian basin lying northeast of Mitchell afford a useful supply for farm and domestic purposes, but they have not the force and volume necessary for power and irrigation on a large scale. The extent of the basin is quite definitely known, for there are numerous well borings throughout its area and around its margin. Its area is, shown on the map, Pl. LXIX. Another small area of similar waters occurs in the central part of Turner County, in the basin at Turkey Ridge Creek. It supplies water to over a score of farms and is similar in every respect to the larger area northeast of Mitchell. Several small detached areas occur in Hutchinson, Lincoln, and Moody counties. The waters in the chalk or Niobrara formation occur mainly within the same basin as the drift waters northeast and westward of Mitchell, and quite a number of wells in that basin receive large supplies of excellent water from the chalk beds, at depths averaging about 200 feet.

In the western Coteau area there is a wide tract of elevated country in which there appears to be no prospect for artesian waters. The area is undoubtedly underlain by the Dakota sands and sandstones, containing large volumes of water, but the head of these waters is not sufficient to carry them to the surface of this elevated region. As no wells have yet been bored within the area to a sufficient depth to ascertain the underground conditions, we have to depend on the evidence of wells in the surrounding lowlands for a basis of prediction as to the area in which a flow may be expected. The head which the water has at Jamestown is sufficient to raise the water to an altitude of 1,614 feet above sea level, but the land to the westward, from Windsor to beyond Sterling, rises several hundred feet higher than this. Of course if the pressure or head of the water increases westward, some parts of this elevated region may be within reach of artesian flows; but of this there is now no definite evidence, and the probabilities are strongly negative. At Ellendale the head is sufficient to raise the water to an altitude of 1,727 feet above sea level, or about halfway up the steep slopes of the highlands which extend westward from Lorraine to the edge of the Missouri Valley. The Ipswich well indicated sufficient head to elevate the water to an altitude of 1,775 feet, the Faulkton well to 1,664 feet, and the well near Orient to 1,865 feet, all of which would be insufficient to reach the surface in the wide, high area lying a short distance westward and extending nearly to the Missouri.

Along the line of wells extending from St. Lawrence to Pierre the head of the artesian waters presents some curious variations. About St. Lawrence and Miller it averages an amount sufficient to raise the waters to an altitude of 1,860 feet. At Highmore its altitude increases to 1,920 feet, at Harold it has decreased to 1,862 feet, and at Pierre is only 1,820 feet. The amount at Highmore is sufficient for the waters to reach the surface over a narrow area extending across the Coteau, but insufficient to carry them to the surface in the high region of Ree Heights, and probably also the ridge extending northward through Edwin, Sedgwick, Goudyville, and Cramer. The pressure at Pierre indicates that artesian waters may be expected over all the surrounding lands to an altitude of 1,820 feet. Whether the head increases westward under the higher lands or decreases as it does from Highmore and Harold to Pierre can not be stated. How far the artesian waters extend up the Missouri is not now known, but it is thought they may reasonably be expected far beyond Bismarck. The well which is soon to be sunk at the Cheyenne Agency, opposite Forest City, will give additional evidence as to the depth and pressure of the water in this direction.

In the series of wells extending along the Chicago, Milwaukee and St. Paul Railroad from Mitchell to Chamberlain there is a progressive increase of pressures to the westward as far as Kimball, and along this line, in the wells to the southward, the head is known to be sufficient to carry the water to the highest lands, excepting the summits of the Bijou Hills. The increase of pressure from east to west in this region may possibly continue far beyond the Missouri River, and if this is the case artesian flows may be had over wide areas of the now arid Plains region. Much of this region lies above an altitude over 2,000 feet, and to the southwestward the altitudes rapidly increase to about 2,700 feet in the vicinity of the Rosebud Agency. The deep well now in progress in the center of the Rosebud Reservation will indicate the conditions under which the artesian waters extend west of the Missouri River in that region, but we must wait for this evidence before any definite predictions can be made.

The eastern margin of the artesian area extends along the steep western slope of the eastern Coteau, crosses the western side of Miner County, extends up the Redstone Valley some distance, then, passing westward nearly to Mitchell, it extends along the eastern side of the James River Valley nearly to its mouth. In Clay County the pressure is only sufficient to give artesian flows in the lower portions of the valleys. At Vermilion the head is insufficient to carry the waters to the top of the table-land, and its amount declines gradually as the Missouri is descended, until at a point near Burbank the waters will not rise above the level of the river. At Elk Point extensive tests have been made which demonstrate beyond any question that the termination of the artesian flow is some distance westward. Along the Missouri bottom from Yankton to Burbank, up the Vermilion bottom lands to Centerville, and up the valley of Clay Creek nearly to the western boundary of Clay County, there are many wells which yield abundant water supplies.

The heads at Britton and Langford and Andover are insufficient to carry the waters to a level more than halfway up the slopes of the Coteau to the eastward, and at Dolau and Iroquois they fall short to a still greater degree. In the lowlands north of the end of the eastern Coteau artesian flows reach the surface at Rutland and Ransom with considerable head, and the area of available artesian flows appears to be extensive in this region. At Tower City the head may prove insufficient to carry water to the level of the higher points on the moderately high land of the ridge that extends throughout Alta, unless the increase of pressure westward, as indicated by the Jamestown well, begins near Tower City.

WELLS AND WELL PROSPECTS IN SOUTH DAKOTA.

BROWN COUNTY.

Some of the earliest attempts to obtain artesian waters were made in this county, and their success was so great that they gave much impetus to the development of this resource in other portions of the State. There is a group of wells at Aberdeen, and there are others scattered quite widely over the county. Several are not now in use, owing principally to being clogged up with sand, but all those that went to a considerable depth found large supplies of excellent water under great pressure.

The following is a list of all the wells from which returns have been received:

List of artesian wells in Brown County, S. Dak.

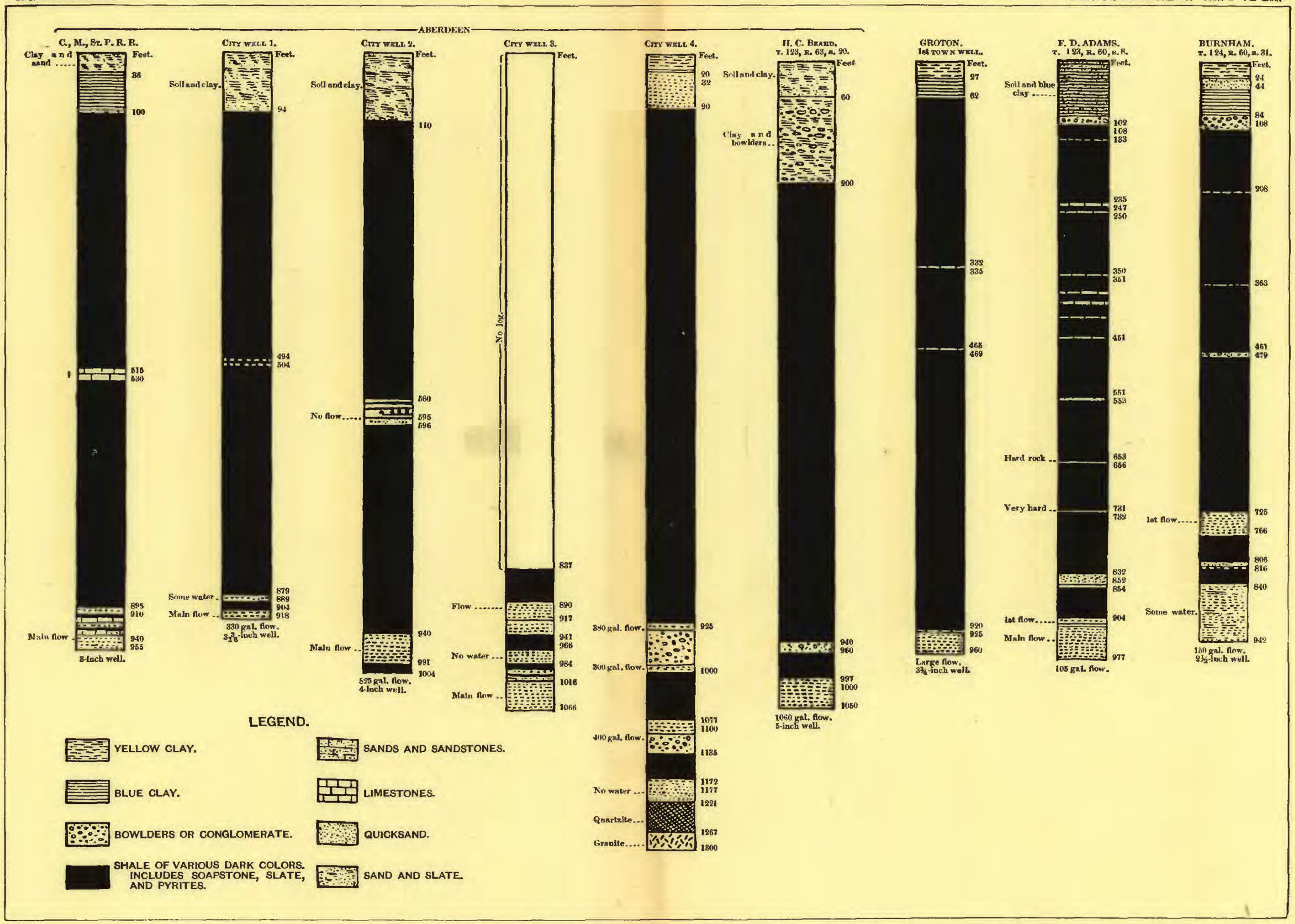
Location, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
	Feet.	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
Aberdeen:					
City well No. 1	918	$3\frac{3}{16}$	879 905	40	330
City well No. 2	1,004	6–4	946	62	825
City well No. 3	1,066	8–2	910	....	....
			921	....	....
			1,020	....	Many.
City well No. 4	1,300	8–4½	920	....	380
			995	....	300
			1,077	85	400
Railroad Company	955	8–3	925	....	....
			940	100	Many.
O. S. Cook, T. 123, R. 63, sec. 17	1,117	4½	925	....	....
			1,090	....	....

List of artesian wells in Brown County, S. Dak.—Continued.

Locatian, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
Aberdeen—Continued:	*Feet.*	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
Beard well	1,050	6–5	1,000	138	1,060
Weed well, T. 123, R. 63, sec. 18	1,015	4½	928	125	300
Columbia, city well	964	4½	721	....	Few.
			801	....	Few.
			862	....	Several.
			892	....	Several.
			927	160	940
C. Flanders, T. 126, R. 61, sec. 31	965	....	681	....	Few.
			724	....	Few.
			782	....	Few.
			912	135	....
H. L. Heman, T. 125, R. 61, sec. 3	716	....	560	....	....
Frederick, city well	1,139	6–4½	985	....	4
			1,045	70	135
Krouschnabel, T. 127, R. 63, sec. 12	856	....	....	....	....
Abbott & Morgan, T. 127, R. 63, sec. 21.	800	....	....	....	....
Groton:					
Town well No. 2	922	6–3	889	135	830
Town well No. 1	960	5 3/16–3¾	925	....	....
F. D. Adams, T. 123, R. 60, sec. 8	977	....	906	....	....
			917	80	105
W. A. Burnham, T. 124, R. 60, sec. 31	942	4–2½	725	....	....
			840	137	150
Westport, T. 126, R. 64, sec. 32	1,030	6	....	35	....

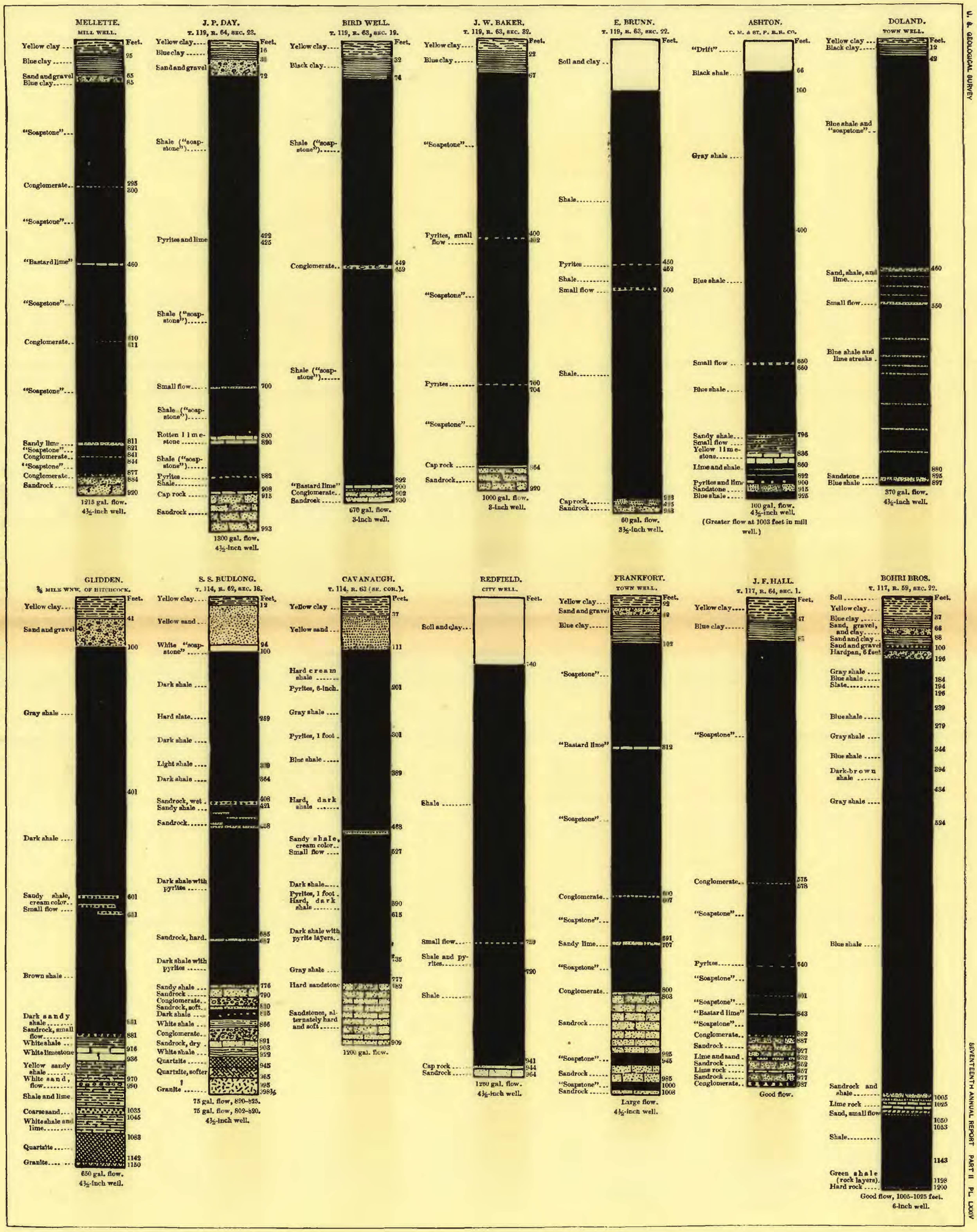
The logs of a number of Brown County wells are given in Pls. LXXII and LXXIII.

The wells at Aberdeen have developed three powerful flows of water, all of which are now being drawn upon for town use. The deepest boring reached a depth of 1,300 feet, and, it is claimed, penetrated quartzite and then granite bed-rock for some distance. These three water horizons may be continuous throughout the county, but as no other wells have gone sufficiently deep to reach the deepest one, and the others can not be definitely correlated in the various wells, there is some uncertainty in this regard. The Beard well, a short distance east of the city, obtained a large supply of water under greater pressure, apparently from the second flow at Aberdeen, and this is thought also to be the horizon of the waters at Groton, Andover, and possibly some



LOGS OF WELLS IN SOUTHERN HALF OF BROWN COUNTY, SOUTH DAKOTA.

LOGS OF WELLS IN SPINK AND CLARK COUNTIES, SOUTH DAKOTA.



other wells. Nearly all of the wells have found two or more flows, but these can not always be traced from well to well. The pressures in the wells of Brown County present considerable variability, notably at Aberdeen, where in some of the wells the pressure seems exceptionally low. The lower pressures at Frederick and in the Westport well are also exceptional. The pressures are, however, sufficient to carry water far above the level of the highest lands in the county, and there can be no doubt in predicting artesian flows throughout the area. The county is characterized by its level surface, which is similar to that of Spink, Beadle, Sanborn, and a few other counties of the James River Valley region.

EDMUNDS COUNTY.

The well at Ipswich is the only one in this county that flows, but there can be no uncertainty as to the extension of the artesian waters throughout the eastern half of the county. The Ipswich well was sunk in 1885 for city supply, and it found a large volume of water at a depth claimed to be 1,265 feet by the borers. The diameter was 4½ inches at the top and 3¾ inches at the bottom, and the pressure varied from 120 to 85 pounds. Mr. Nettleton's measurements of pressure in 1891 indicated a pressure of 106 pounds at that time. The well was badly constructed, for it finally clogged up in 1891. An attempt to repair the well was not entirely successful, and the present greatly diminished supply appears to be from a depth of 1,000 feet, or the first flow. The pressure of the water in this well indicated a head sufficient to raise it to a level of 1,775 feet above sea level, which is a somewhat greater head than that in the wells of Aberdeen, just eastward. This pressure is, however, insufficient to yield flowing wells in the elevated district about Roscoe and westward. As this district rises quite rapidly along a nearly north and south line extending across the county, the area in which artesian flows may be expected is quite sharply delimited. It is shown in map, Pl. LXIX, and the relations of the water-bearing beds and pressure are shown in section 2, Pl. LXXI.

A well at Roscoe was sunk to a depth of 360 feet, where it was discontinued in a bed containing water of quite a salty character, which rose to within no great distance of the surface. A number of other pump wells obtain excellent water at a depth of 300 feet, but the supply is not large. Larger volumes occur at 250 feet, but the water is usually salty.

MARSHALL COUNTY.

There are a number of wells in the lowlands in the western part of this county, which indicate the eastward extension of the artesian water so extensively developed in Brown County. They are at Newark, Britton, Langford, and Burch, and they obtain their waters from a depth averaging about 1,000 feet. The Newark well furnishes power to run a 20-barrel flour mill. Its depth is 940 feet, bore 8 inches at top and 6 inches at bottom, closed pressure 125 pounds, and it has been estimated to yield 600 gallons per minute. Small flows were encountered at 420 and 480 feet; a larger flow in sands extending from 900 to 910 feet, then 18 inches of iron pyrites, below which was the main flow. The bottom pipe extends into this, and is perforated with three-quarter-inch holes for a length of 45 feet. The waste water from this well covers a lake of about 100 acres to a depth of from 4 to 8 feet. The well at Langford is 1,050 feet deep, 6 inches in diameter, and runs a large flour mill. It is estimated to yield between 400 and 500 gallons per minute. The pressure is stated to be 60 pounds, which is much smaller than should be expected from the experience of the Britton, Andover, and other wells. The first flow was reported at 940 feet, and the quality of the water was excellent. The supply at 1,050 feet is of muddy water. The Britton well belongs to the town. Its depth is 1,004 feet, diameter 8 inches at top, 3½ inches at bottom, pressure 115 pounds, yield 600 gallons per minute, temperature of water 64°. The first flow of any importance was encountered at 880 feet, and the main flow began at 976 feet. The log of this well is shown in fig. 51. The well at Burch was sunk for irrigation. Its depth was not reported.

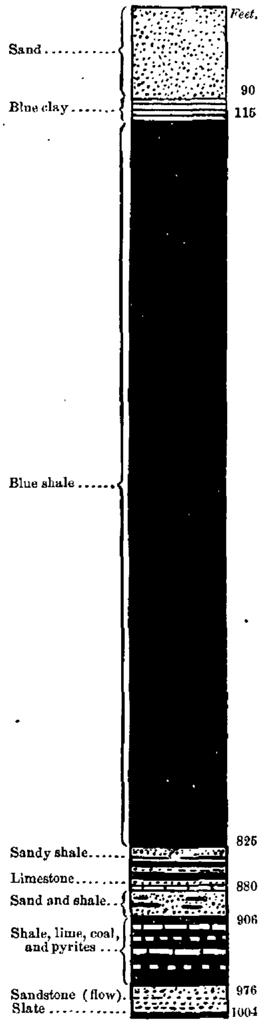


FIG. 51.—Log of town well at Britton, S. Dak.

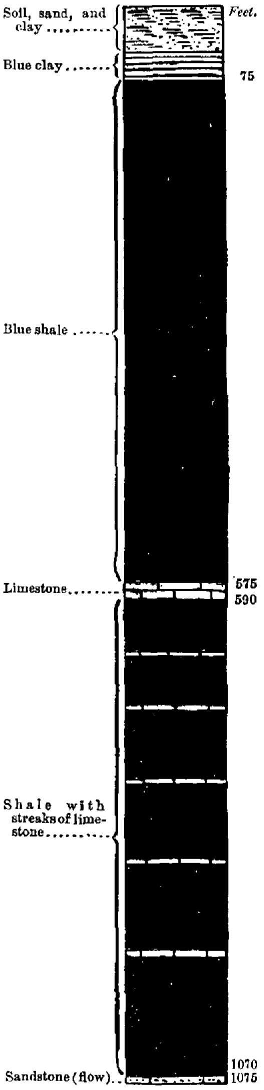


FIG. 52.—Log of well at Andover, S. Dak.

The pressures in these wells indicate that the head of the artesian water is not sufficient to afford surface flows in the elevated region in the central and eastern portions of the county, although, doubtless, water-bearing beds extend under the highlands. The area in which flows may be expected is represented on the map, Pl. LXIX.

DAY COUNTY.

Artesian waters in Day County have been tapped at Andover, where a large flow was obtained at a depth of 1,075 feet. This well and the well at Langford, in Marshall County, indicate the eastward extension of the artesian waters into the county, but the pressure of these waters has been found to be insufficient to carry them to the surface in the highlands lying eastward. At Webster a boring was made some time ago to a depth stated to have been 1,400 feet. Only a small flow was found at 1,100 feet, but this was to be expected when we consider the difference in altitude between Andover and Webster and the head of the artesian waters as indicated by the pressure of the wells at Andover and Langford. The pressure of the Andover well was reported by Colonel Nettleton to be 65 pounds in 1891, which indicates sufficient head to carry the water to an altitude of 1,655 feet above sea level. At Langford it was considerably less. The area of Day County which is thought to be within reach of artesian flows is indicated in the map, Pl. LXIX, and the relations of the water-bearing beds, head, etc., are shown in section 2, Pl. LXXI.

Andover well has a bore 6 to 4½ inches, pressure of 90 pounds, and flow of 300 gallons per minute. The log is shown in fig. 52. The water horizon is the same as that found in the Groton well, and probably also the Beard, and in some of the Aberdeen wells.

SPINK COUNTY.

There are flowing wells at many points in this country, and they all yield, or have yielded, abundant supplies of excellent water under great pressure. The depths are between 900 and 1,065 feet, and in most cases two or more flows of water have been found.

The following table sets forth the principal features of the wells:

Wells in Spink County, S. Dak.

Location, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
	Feet.	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
Northville	980	9-6	875	156	1,900
			956	....	....
Mellette:					
Flour mill	920	6 -4½	884	165	1,320
Hunter farm, T. 119, R. 64, sec. 4	1,065	8 -6	904	....	1,200
E. Brum, T. 119, R. 63, sec. 22	958	....	500	....	....
			880	....	....
			925	141	60

Wells in Spink County, S. Dak.—Continued.

Location, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
	Feet.	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
J. W. Baker, T. 119, R. 63, sec. 32	920	4½-3	402		
			871		894
J. P. Day, T. 119, R. 64, sec. 23	993	6 -4½	700		
			915	135	1, 300
Bird well, T. 119, R. 63, sec. 19	930	4½	902	153	670
Redfield, town well	964	6¼-4½	750		
			944	177	1, 260
J. F. Hall, T. 117, R. 64	987		890		
			927		
Redfield, Hassell & Myers	1, 025	6			1, 900
Frankfort:					
Town well	1, 008	8 -4½	803		
			865		
			945		
			1, 000		
Blaine well, T. 116, R. 62, sec. 4	895	4½	875		600
W. D. Craig, T. 117, R. 62, sec. 32	950	4½	870		350
G. W. Motley, T. 115, R. 61, sec. 7	1, 050	8 -4½	840	87	75
Doland	897	4½	500		
			880	122	370
Do	957			112	600
James Lebrie, near Doland	(*a*)				
Ashton:					
Chicago, Milwaukee and St. Paul Railroad	925	6 -4½	650		
			795		
			900	60	100
Mill	1, 003	8		150	2, 000
Conde	960	4½			
Turton, town well	920	4½			1, 300
J. A. Glidden, T. 114, R. 63, sec. 32	1, 150	6 -4½	1, 070	50	550
Cavanaugh, T. 114, R. 63, sec. 26 ?	909		876		1, 200
S. S. Budlong, T. 114, R. 62, sec. 18	1, 000	6 -4½	790	125	150
			820		
T. S. Everitt, T. 114, R. 62, sec. 30	909	4½	840	150	1, 000

a No data.

These wells indicate relative uniformity in the position and relations of the principal flows of water over the greater part of the area, but the minor flows present considerable variation in occurrence. The principal water horizon appears to be about 50 feet below the top of the Dakota sandstone series, and to lie relatively level over a wide area.

RISDON WELL, NEAR HURON, SOUTH DAKOTA, THROWING A 10-INCH STREAM TO A HEIGHT OF 12 FEET.

As the wells are in nearly all portions of the county, they indicate a general extension of the artesian water, and the head of this water, as indicated by the pressures, is sufficient to bring it far above the surface throughout. This surface is very level, and were it not for the depressions cut by the James River and its branches it would be almost a perfect plain. This plain has an altitude of about 1,300 feet above sea level, and the head above sea level of the artesian flows is over 1,590 feet, with the exception of the Motley and Glidden wells. The low pressures and reduced yields of these two wells are quite exceptional and are difficult to explain, for the boring extends entirely through the Dakota sandstones. These features, however, appear to be in some way related to the presence of a quartzite and granite ridge, which rises into the Dakota sandstone, as shown in Pl. C. The quartzite and granite were penetrated in the Glidden and Budlong wells, and the bed rock, presumably quartzite, was reported at the bottom of the Motley well. The principal flow of the Glidden well is from a sand bed extending from 970 to 973 feet, and, as shown in Pl. LXXIV, the Dakota sandstone here appears to include no large bodies of sand or sandstone, as in the wells farther northward. The influence of the quartzite and granite ridge on the pressures in southern Spink County are shown in Pl. XCVIII.

CLARK COUNTY.

This county lies on the western slope of the east Coteau, and is in greater part at an altitude too high for artesian flows. In the western tier of townships large flows and good pressures may be expected, but as the slope is ascended eastward an altitude is soon attained in which no flow can be obtained. This altitude is approximately 1,680 feet in the northern portion of the county, 1,650 feet in the central portion, and 1,600 feet in the southern portion.

The only flowing well in the county of which we have learned is on the farm of Bohri Brothers, in SE. ¼ of sec. 22, T. 117, R. 59, or about 1½ miles northeast of Raymond, at an altitude of about 1,490 feet above sea level. The total depth of the boring was 1,200 feet, but the casing extended only 1,075 feet. The diameter was 6 inches, and the lower 40 feet were perforated. Flows were found in sands from 1,005 to 1,025 feet and from 1,050 to 1,053 feet. The well was finished in the spring of 1892, and the water continued to flow with a closed pressure of 80 pounds until the winter of 1893, when the casing became clogged up, and the flow diminished to a small drip. The log of the boring is given on Pl. LXXIV, and the stratigraphic relations are shown in section 3, Pl. LXXI. The water-bearing horizon is in the top of the Dakota sandstone, and probably is the same as the one which supplies the Doland, Andover, Conde, Groton, Turton, and many other wells.

Two attempts have been made to obtain the deep-seated waters at the village of Clark. In both cases the tools were lost at a depth of about 1,200 feet, and the borings were abandoned. As shown in section 3, Pl. LXXI, the water-bearing beds probably lie at a depth of about 1,300 feet at Clark, but the head is not sufficient for a surface flow at that locality. No doubt a well to this depth would obtain a large volume of water, which would rise to within about 110 feet of the surface at Clark and afford very satisfactory force-pump wells.

FIG. 53.—Log of well in T. 117, R. 68, sec. 18, near Orient, Faulk Co., S. Dak.

FAULK COUNTY.

Only two deep wells have been sunk to the artesian waters in this county, but their experience was satisfactory. They were near the central part of the area, and indicate the extension of the waters westward from the James River Valley, where, in the adjoining county of Spink, they furnish large supplies to many wells.

The well at Faulkton is stated to draw its waters from a depth of 1,032 feet, but the contractors claim that its original depth was 1,296 feet. It was not properly constructed, and at one time completely clogged up. The flow is estimated at 100 gallons per minute, and the pressure varies from 25 to 34 pounds per square inch. The other well is about 4 miles north by east of Orient. It had a depth of about 1,215 feet, a flow of 950 gallons per minute, a pressure of 130 pounds to the square inch, a diameter of 6 to $5\frac{1}{4}$ inches, and a temperature of 75°. It is now clogged up. It is reported that several flows were found, those at 394, 1,050, 1,070, and 1,165 feet being the principal ones. Its log is given in fig. 53. As shown in section 3, Pl. LXXI, the lowest waters in the Orient and Faulkton wells were in the same horizon in the Dakota sandstones, which is probably the same one as at Redfield and Frankfort. The upper horizons are less definitely correlated, but they appear to be at the top of the irregular upper surface of the Dakota sandstone. The pressure exhibited in the Orient well is sufficient to raise the waters to an altitude of 1,865 feet. Possibly the original pressure at Faulkton was equally great. This head is sufficient to yield an artesian flow in all except the western tier of townships of the county, and T. 117, R. 71, which are elevated considerably above 1,850 feet in greater part. In the eastern portion of the county, where the country is less elevated, abundant water supplies may be expected at a depth of between 1,000 and 1,100 feet, and although the head of the waters decreases somewhat, the rate is less than that of the downward slope of the land, and the high pressures are sustained.

Shallow waters, available for farm use by pumps, occur in considerable volume in some portions of the county, but there are belts of greater or less width in which water is absent or very scarce at moderate depths. There is a belt of this character just east of Rockham, in which wells to 300 feet in depth obtain no water supplies. Northwest to Miranda there is a belt in which only small supplies are obtained at 125 feet, and in the slopes north of Snake Creek Valley great difficulty has been experienced in obtaining water in dry seasons. About Seneca the wells are seldom less than 95 to 160 feet deep, and some have found no water at these depths.

BEADLE COUNTY.

The wells in this county and along the edges of adjoining counties fully indicate that the artesian waters extend under the entire area. These waters lie at depths of from 800 to 1,100 feet in greater part, and appear to be in large volume and under great pressure. The water-bearing beds slope gently to the northward, as shown in section 1, Pl. LXXI, and there are several of them. The principal features of the wells for which we have definite data are given in the following list:

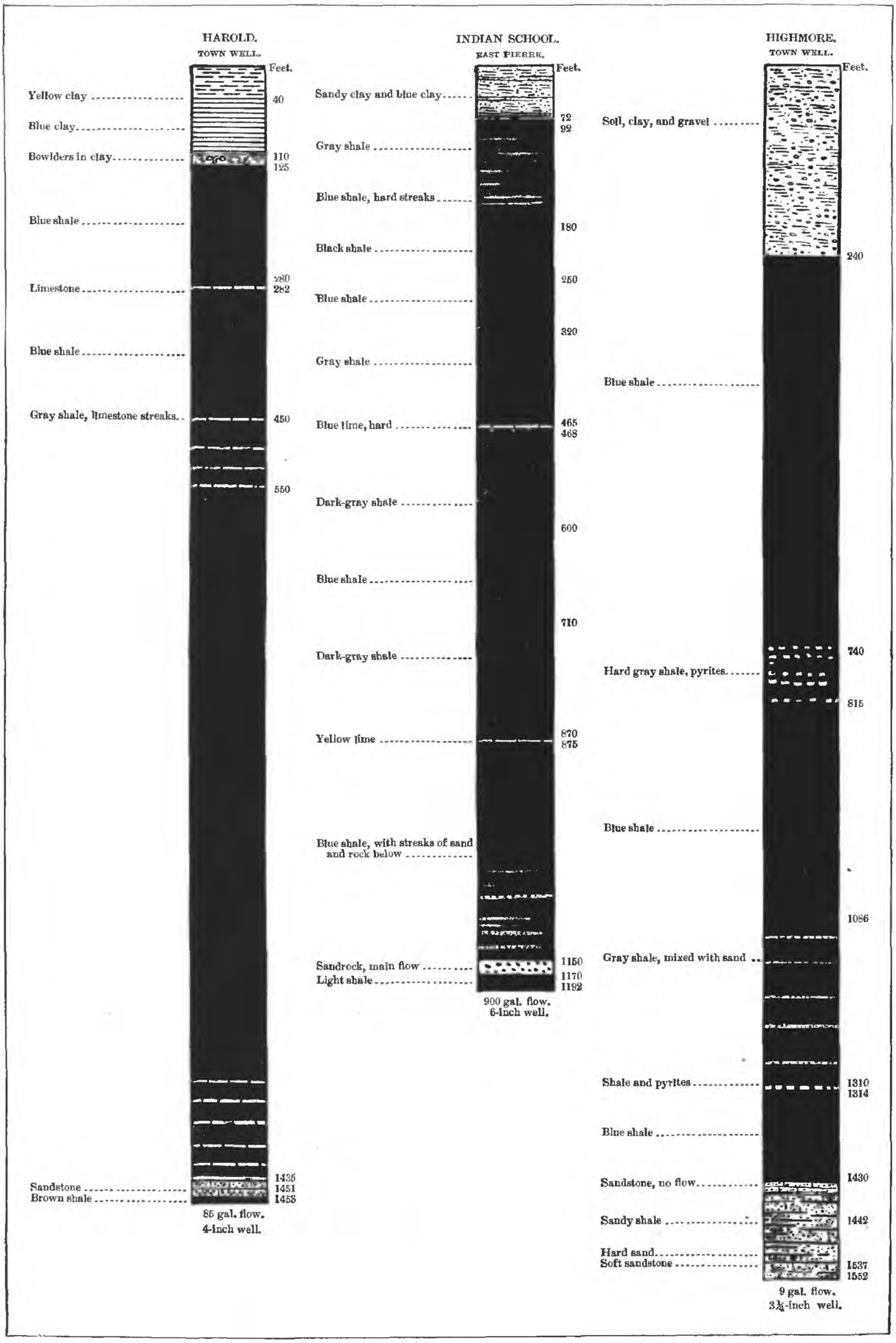
List of artesian wells in Beadle County, S. Dak.

Location, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
	Feet.	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
Hitchcock	953	4½-3¾	924	150	1,260
			950		
Bonilla, T. 113, R. 64, sec. 15	1,066	4½			600
T. 113, R. 64, sec. 29	1,118	4½		175	1,435
Wolsey	930	8 -5	490		
			808		
			858	137	330
			893		
Huron:					
Town well	906	6	712	120	1,500
			772		
Risdon well	960	10 -5⅝	240		
			460		
			510		
			600		
			640		
			690		
			700		
			960	165	2,250

List of artesian wells in Beadle County, S. Dak.—Continued.

Location, etc.	Depth.	Diameter.	Distance from the surface to top of beds yielding flows.	Closed pressure per square inch.	Yield per minute.
Huron—Continued:	*Feet.*	*Inches.*	*Feet.*	*Pounds.*	*Gallons.*
Melville well, 1 mile southwest	1,080	5½	900	....	1,500
Ward well, 2½ miles southwest	847	6 -4	776	....	....
			826	120	600
Wilcox well	1,040	8	756	....	350
C. M. Bell, T. 111, R. 61, sec. 31	792	3	734	....	200
T. A. White, T. 111, R. 61, sec. 19	836	3	....	....	360
A. B. Melville, T. 110, R. 62, sec. 11	1,080	5½	900	....	1,500
Richards well	917	6 -4½	770	....	....
			800	....	....
F. B. Brayton, T. 109, R. 62, sec. 30	813	3	500	....	....
			800	125	250
M. O. Besserud, T, 110, R. 60, sec. 29	930	4½	748	....	....
			920	100	930

The well-known group of wells about Huron produces a large amount of water under great pressure. The Risdon well, one of the earliest in the State, and the Melville well draw from a horizon far down in the Dakota beds. A view of the Risdon well flowing its full capacity is given in Pl. LXXV. It is quite singular that the Wilcox 1,040-foot well in Huron did not find this water, for if it were sunk to the depth claimed it must undoubtedly have passed through the beds which yield the large flow under great pressure in the Risdon well, a short distance northeast. The water-bearing bed near the top of the Dakota sandstones appears to be continuous throughout all the wells and to be the source of supply in the wells to the south, the Iroquois well to the east, the group of wells around Hitchcock on the north, and the Wolsey well on the west. The Wolsey well appears to have penetrated to the intermediate stratum of water which yields the principal supply of the town well in Huron and a small flow of the Ward well, but at Wolsey its volume is very slight. It is claimed that the Wolsey well reached bed rock, and if this is the case no doubt the lower waters are cut off by the ridge shown in Pl. LXX and in profile in section 4, Pl. LXXI. In sections 1 and 4 in Pl. LXXI the relations of the underground waters of Beadle County are shown so clearly that I believe no detailed discussion of their prospects is necessary. Logs of many of the wells are given in Pl. LXXVI. The county lies at such a low altitude above sea level that its entire area is within reach of the artesian waters.



LOGS OF WELLS IN HYDE AND HUGHES COUNTIES, SOUTH DAKOTA.

KINGSBURY COUNTY.

The artesian conditions in this county are almost precisely similar to those in Clark County. The western tier of townships lies at altitudes sufficiently low to be within the reach of artesian flows, while to the eastward in the higher Coteau country the land is too elevated for flows from the Dakota sandstone horizon. The principal well in this county that reaches the deep waters is at Iroquois. It has a depth of 1,115 feet and yields about 1,000 gallons per minute. Small flows were found at 400 and 600 feet and the main flow is from sands at from 850 to 600 feet. The closed pressure was reported by Colonel Nettleton to be 67 pounds per square inch in 1890. The log of the boring is given in Pl. LXXVI. The water horizon appears to be the same one which supplies the deeper wells about Huron, but no definite correlation is possible.

There is also a flowing well on the farm of Mr. Langley in sec. 30, T. 109, R. 58, which is 600 feet in depth and which is said to yield a fairly good supply of water. The diameter of the well is 2 inches. The flow probably comes from the thin local bed of sand reported at about the same depth in the Iroquois well. At De Smet, on the summit of the Coteau, the municipal authorities have had a boring sunk to a depth of 1,610 feet without finding an artesian flow. Water-bearing beds were found at 200, 700, 1,100, and 1,400 feet, but the waters were not in large amounts nor under sufficient head to rise to the surface. The last 400 feet were through rock. The boring cost nearly $8,000.

Major Coffin has reported a boring 800 feet deep at Arlington which obtained no flow, but no details have been furnished relating to it. Its position is shown in section 4, Pl. LXXI.

The nonartesian waters of Kingsbury County are of somewhat variable occurrence. At some localities it has been necessary to go to a depth of over 600 feet, but many wells obtain abundant supplies from 150 to 300 feet. Shallow wells from 20 to 150 feet deep are satisfactory only in restricted areas along the deeper depressions, and even some of these wells dry up in the autumn. In wells over 250 feet deep the waters usually rise to within 30 to 50 feet of the surface. In the depression around Lake Preston some of the wells rise to within a very short distance of the surface, and in one or two cases slight overflows were reported.

HAND COUNTY.

In a belt of considerable width extending from east to west across the center of this county there is a series of wells which indicate very clearly the relations of the underground waters. Their depths range from 1,137 to 1,375 feet, for the region is part way up the slope of the western Coteau. The greater number of these wells have been sunk by townships, and they are intended for irrigation and stock. In the following list are given the principal features of those wells for which we have data:

List of artesian wells in Hand County, S. Dak.

Location, etc.	Depth.	Depths to flows.	Diameter.	Yield per minute.	Closed pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
St. Lawrence, T. 112, R. 67, sec. 7.....	1,272	1,070 1,272	....	Few.	40 ....
R. T. Sedam, T. 112, R. 67, sec. 18.....	1,343	1,315	3	350	125
John Baldwin, T. 112, R. 67, sec. 33...	1,375	1,343	3	1,000	119
Township well, T. 112, R. 68, sec. 7...	1,200	....	4	50	....
W. H. Smith, T. 112, R. 68, sec. 10.....	1,140	1,110	3½	....	....
Miller, T. 112, R. 68, sec. 10............	1,139	1,112	6¼-4½	360	120
Township well, T. 113, R. 69..........	1,200	....	....	....	....
Township well, T. 113, R. 67, sec. 25..	1,137	1,087 1,127	6-3	480	....

The first well in Miller clogged up about two years ago, and it was thought by many that the cessation of flow was due to the water giving out. In order to test the matter another well was sunk, and the same strong flow was found as in the first well. The log of the Miller well is given in fig. 54.

There is some discordance in the experience of the several wells about Miller and St. Lawrence as to the position of the water horizon, but they all indicate that large flows of excellent water are to be had. The wells south of St. Lawrence appear to derive their waters from somewhat deeper horizons than those along the line of the railroad, and they have not reported the shallower waters. The well on the higher lands west of Miller reached the horizon of the Miller waters at a depth of 1,200 feet, and the well on the lower slopes in T. 113, R. 67, also appears to derive its water from this horizon, which indicates that the water-bearing bed is nearly horizontal in this portion of the county. The pressures in the Miller and St. Lawrence wells indicate that the water has sufficient head to rise to an altitude averaging about 1,860 feet above sea level, and the pressure in the well at Highmore indicates that this amount increases somewhat to the westward. This head is insufficient to bring the waters to the surface in Ree Heights and in portions of the adjacent highlands as shown in Pl. LXIX, but all other portions of the county are probably within the reach of artesian flows. Of course the pressure of these flows would be less in the higher lands than it is lower down, but it should also be borne in mind that the head increases to the westward in the region of higher lands. The well north of Orient, in Faulk County, indicates sufficient head at a depth of about 1,200 feet to carry the water all over the northern portion of the county, excepting probably in a small area in its northwestern corner.

WELL AT WOONSOCKET, SOUTH DAKOTA, THROWING A 3-INCH STREAM TO A HEIGHT OF 97 FEET.

HYDE COUNTY.

There is but one deep flowing well in this county, but it throws important light on the artesian-well prospects in this portion of the western Coteau. The well is at Highmore, at an altitude of 1,890 feet. Its depth is 1,552 feet, diameter 6 inches, flow about 9 gallons per minute, and the pressure is stated to be 12 to 15 pounds per square inch. In the Resources of Dakota for 1887 its flow was given at 14 gallons and pressure 25 pounds, but later measurements reported by Mr. Coffin give smaller figures. The temperature of the water is 72°. The water-bearing bed was entered at 1,537 feet. Water was found also in a bed extending from 1,430 to 1,442 feet, but it did not flow out of the well. The log is given in Pl. LXXVII. While the pressure of the water in this well is relatively low, it indicates a greater head above sea level than that of any other well in the region. It is equivalent to a rise of the waters to an altitude of 1,920 feet above sea level. This head is sufficient to bring waters to the surface over a limited area on the slopes of the high ridge which passes through the center of Hyde County. Of course this head may decrease in the regions north and south of Highmore, as it does to the west, as indicated at Harold, so that we can not make a definite prediction as to the precise altitude at which artesian waters may be expected in the higher lands in Hyde County. In Pl. LXIX, I have attempted to indicate approximately the area of which the elevation appears to be sufficiently low for artesian flows, but it should be borne in mind that this is only an approximation and is not based on very definite topographic information or knowledge as to the possible variation of the head of the waters.

FIG. 54.—Log of town well in Miller, Hand Co., S. Dak.

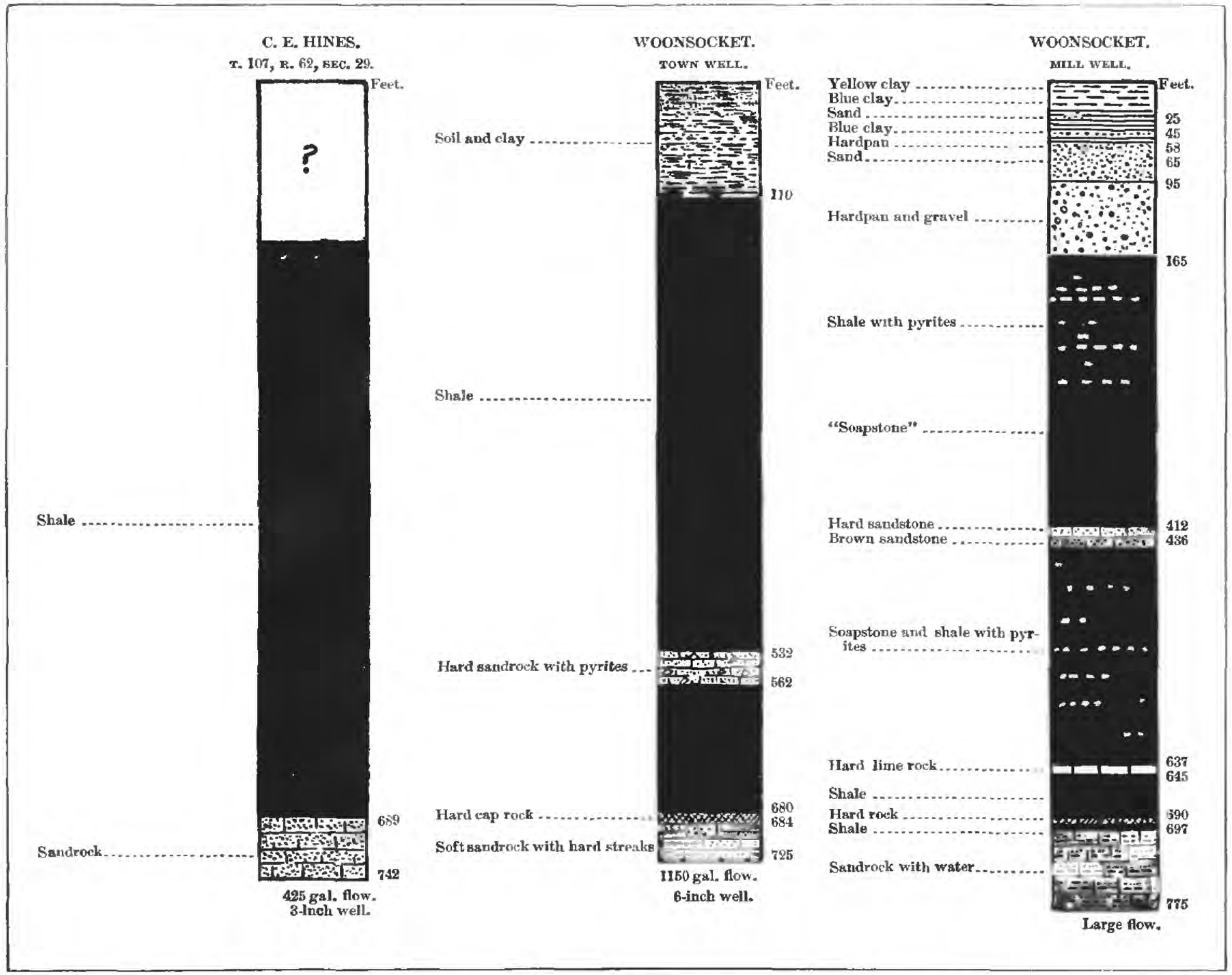
HUGHES COUNTY.

There are three deep flowing wells in this county—two in the Missouri bottom at Pierre and East Pierre, and the other on the relatively high lands at Harold. The well in Pierre is at the Hotel Locke, to which it furnishes water at a temperature of 92° for the bathing pool. Its depth is 1,160 feet. The flow is stated to be about 600 gallons per minute. The well at East Pierre is at the Indian school, and is intended for domestic water supply and irrigation of the gardens. Its depth is 1,192 feet, but the main flow of water is from a sandstone which extends from 1,150 to 1,170 feet. The flow was about 900 gallons per minute and the pressure about 165 pounds to the square inch, but the well is partially clogged up at present. Its log is given in Pl. LXXVII. The water of both of these wells contains a large percentage of gases, mainly methane, but also ammonia in considerable amount. They are quite highly saline, but notwithstanding this fact the water at the Indian school has proved useful in the gardens. The wells penetrated shales to the top of the sand rock at 1,150 feet, but thin "limestone" beds were reported at 468 and 875 feet, those at the greater depth probably representing part of the Niobrara chalk deposits.

The Harold well was sunk by the town in 1888. It has a depth of 1,453 feet and a bore of 4 inches at bottom. Its flow is claimed to be 84 gallons per minute, and a closed pressure of 27 pounds per square inch was reported. The water has a temperature of about 95°, and it is much less saline than that of the Pierre wells. The log is given in Pl. LXXVII. The main flow of water is in sandstone extending from 1,435 to 1,451 feet. A small flow was found at 1,000 feet, and there were several others at intervals near the bottom of the shale.

These three deep wells indicate that Hughes County is underlain by a large supply of artesian water. Of course the depth to this water is much greater in the higher lands than in the Missouri bottom, and in the northeastern corner of the county the depth will be slightly greater than at Harold. In descending the Missouri below Pierre the depths decrease somewhat, for the beds rise in that direction, and the river also descends materially. From the pressure at Harold it would appear that the water will rise at that place to an altitude of 1,862 feet, and at Pierre the pressure is such that the water would rise to an altitude of 1,820 feet. Medicine Butte is reported to be fully 2,000 feet in height, and the ridge south of Harold is somewhat above 1,900 feet, so that these restricted areas are too high for artesian flows. They are, of course, underlain by the water-bearing beds, and deep wells on these areas would reach the same waters as at Harold and Pierre, but they would fall short of the surface 100 feet or more. In Pl. LXIX are indicated the approximate areas of these high lands.

The shallow waters of the county lie mainly between 100 and 200 feet below the surface in the higher lands, but they are very variable in occurrence, and I have not secured sufficient data for their predictions throughout the county. In the Missouri bottom, and along drains and sloughs, water is usually found in abundant supply, at depths of from 12 to 25 feet, and at some points there are springs in these depressions. The area in which the greatest difficulty is experienced in obtaining waters comprises Byron, the northern half of Dry Run, and the greater part of Pleasant Valley townships.



LOGS OF WELLS IN NORTHWESTERN PORTION OF SANBORN COUNTY, SOUTH DAKOTA.

SULLY COUNTY.

The only well in this county of which I have learned is the boring at Fort Sully, which was sunk in 1884 to a depth of 976 feet, and then abandoned in a bed of quicksand. The experience of the wells at Pierre and Harold indicates without doubt that Sully County is underlain by the water-bearing beds, and that in the less elevated areas artesian flows may be expected. In the valley of Medicine Creek, and on the adjoining slopes, the conditions are probably the same as at Harold, and all the lands below 1,850 feet in altitude are perhaps within reach of artesian flows. The same is the case along the Okobojo Valley, while along the Missouri bottom there is every probability that the same conditions will be found to prevail as in the wells at Pierre and East Pierre, although possibly the waters may be from 50 to 150 feet deeper.

JERAULD COUNTY.

The artesian waters have been tapped by a number of wells in the eastern half of this county, and the conditions were found to be satisfactory for a large supply. The region in which the wells have been sunk is the plain of the James River Valley at altitudes from 1,350 to 1,500 feet above sea level. In the high lands of the Wessington hills and other drift ridges westward no deep borings have been made. The pressure reported in several of the wells indicates that the higher portions of these lands are above the altitude to which the water will rise. The data as to the altitude of the western half of the county are so meager that it is not now possible to indicate precisely the area which is too elevated for artesian flows, but it is shown approximately in Pl. LXIX. A well in the central-northern portion of the county is reported to have a pressure equivalent to a head of about 1,700 feet above sea level, and one in T. 106, R. 64, indicates a head of 1,682 feet. As flowing wells exist in the northwestern corner of Aurora County and the northeastern corner of Brule County, it is believed that all of the southern and southwestern margins of Jerauld County are sufficiently low for artesian flows. The following is a list of wells in Jerauld County:

List of artesian wells in Jerauld County, S. Dak.

Location, etc.	Depth.	Diameter.	Closed pressure per square inch.	Yield per minute.
	Feet.	*Inches.*	*Pounds.*	*Gallons.*
L. Frictner, T. 106, R. 63, sec. 2	715	2	132	200
Frank Campbell, T. 106, R. 63, sec. 6	[a] 760	3-2	110	280
P. Schultz, T. 106, R. 64, sec. 9	880	2½	114	280
Charles Walters, T. 106, R. 64, sec. 15	[b] 816	3	....	10
C. Cladt, T. 106, R. 64, sec. 17	810	2½	....	5
Daniel Schmidt, T. 108, R. 64, sec. 11	799½	2-1¼	....	2
S. H. Abert, T. 108, R. 65, sec. 5	1,057	2½	90	200

[a] Water at 737 feet.

[b] Water at 773 feet.

The experience of these wells indicates that the water-bearing bed lies nearly horizontal or rises slightly to the south and east. Its depth is about 715 feet along the eastern edge of the county, and it lies correspondingly deeper as the land gradually rises westward. There may possibly be two horizons of water-bearing beds, but if so they are not far apart. In the southeastern corner of the county there are also

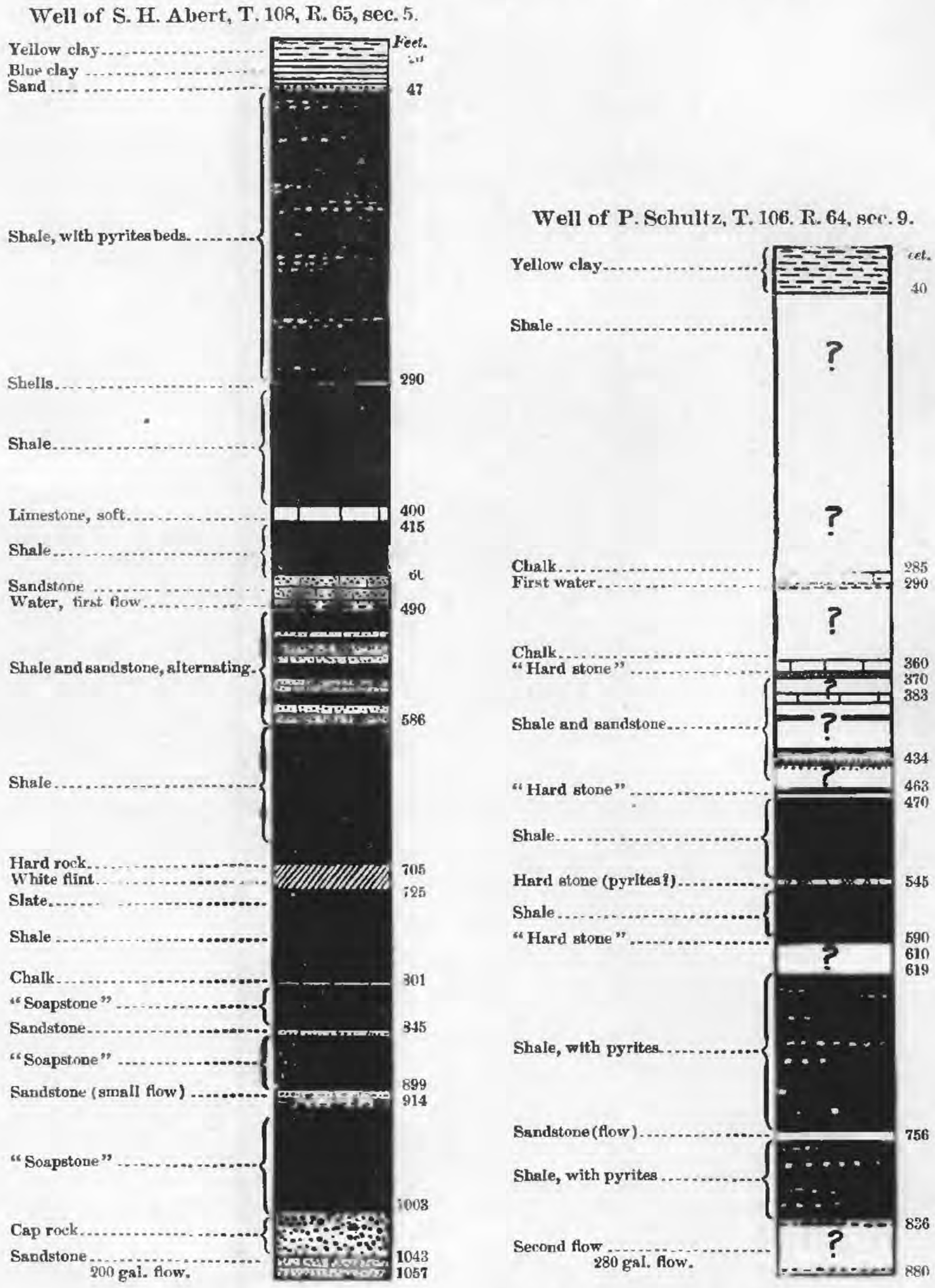
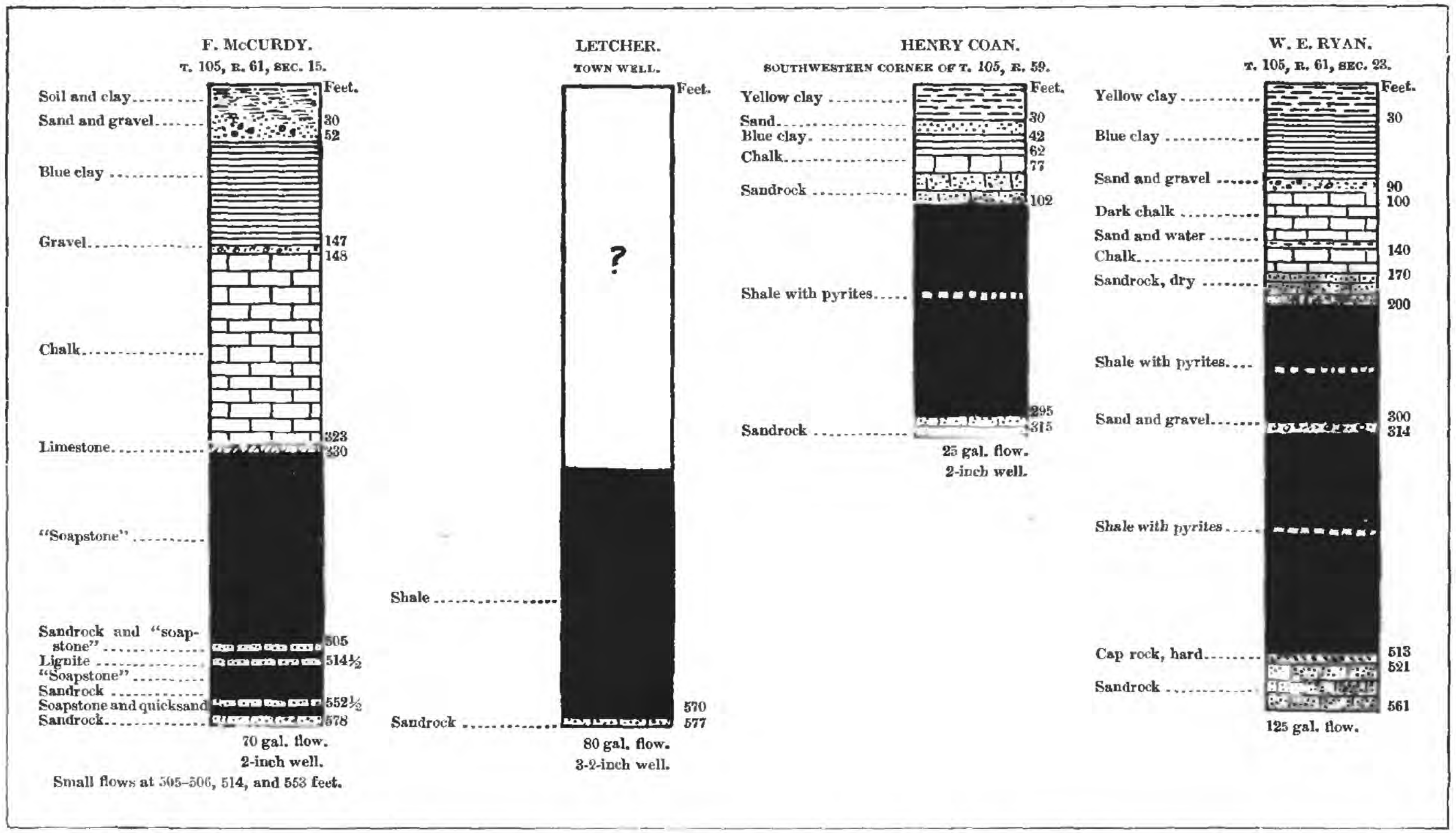


FIG. 55.—Logs of two artesian wells in Jerauld County, S. Dak.

prospects for moderate water supplies at a depth of about 550 feet, such as are found in a few wells in the adjoining counties. Their existence, however, can not be definitely predicted. The relatively small supplies of water in the wells in the above list are due mainly to the small diameters of the casings. Only two logs of Jerauld County wells were obtained; they are given in fig. 55.



LOGS OF WELLS IN SOUTHERN-CENTRAL PART OF SANBORN COUNTY, SOUTH DAKOTA.

The nonflowing waters of the county are reported to be rather irregularly distributed. In the central eastern townships the basal drift beds lying on the chalk yield excellent supplies to pump wells at depths averaging about 130 feet. Further supplies may also be obtained in the chalk at a depth of 300 feet. Sands at the base of the yellow clays furnish water to many shallow wells in scattered localities, but these wells fail in dry weather. Better supplies are found in a thin gravel bed lying beneath the blue clay or in sands under the hardpan below. In the valley which extends along the center of range 66 there are thicker beds of gravel under the yellow clay at depths often only from 12 to 20 feet, which carry a fair supply of good water. In the adjacent hills the water lies at the base of blue clay and occurs very irregularly.

SANBORN COUNTY.

All of this county is underlain by the deeper artesian waters, and the greater part of the area east of James River contains a local basin which lies at no great distance below the surface and yields fair supplies of excellent waters. These shallower waters are mainly in the basal beds of the drift formation or in the underlying chalk, and their occurrence appears to be connected with the rise of the chalk formation to the surface below the drift. The shallower waters have been extensively developed in the region around Artesian village, where there are over a hundred wells. The deeper seated waters have been tapped by a limited number of wells which lie west of James River, mainly in the vicinity of Woonsocket and Letcher. Owing to the rapid upward slope of the water bearing beds to the southward, wells in Sanborn County are at a much less depth than those in Beadle County, and it is found also that the pressures have diminished materially. In the following list are given the locations, depths, and other data regarding the wells which draw from the deeper seated waters:

List of deep artesian wells in Sanborn County, S. Dak.

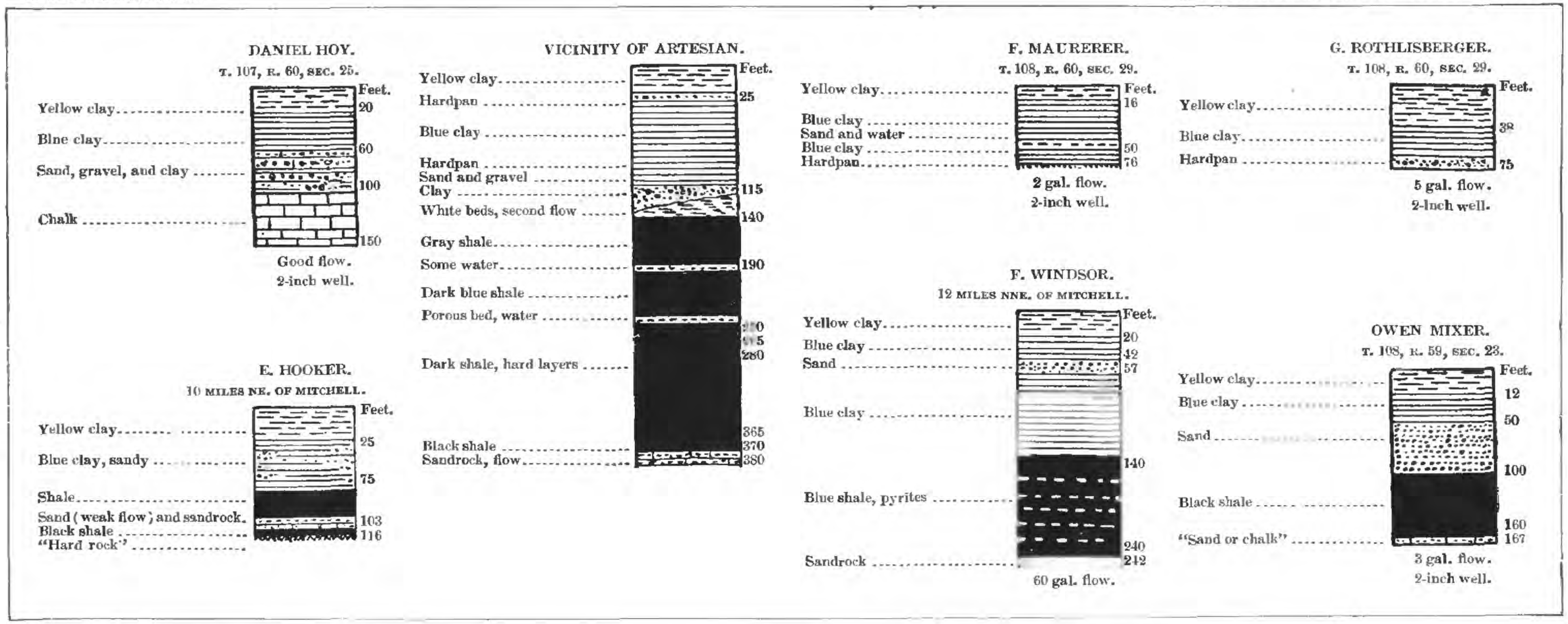
Location, etc.	Depth.	Depth to flows.	Diameter.	Yield per minute.	Closed pressure per square inch.
Woonsocket:	*Feet.*	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
City well	725	684	6	1, 150	130
		645			
Mill well	775	690		Many.	125
		6[illegible]7			
C. E. Hines, T. 107, R. 62, sec. 29	742	689	3	425	130
W. E. Ryan, T. 105, R. 61, sec. 23	561			125	
		300			
Letcher, city well	577	400	3–2		
		570		80	90

List of deep artesian wells in Sanborn County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to flows.	Diameter.	Yield per minute.	Closed pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
F. McCurdy, T. 105, R. 61, sec. 15	578	505	2		
		552		70	
Mark Harris, T. 105, R. 61, sec. 15	584	550	2	80	
C. Quitno, T. 105, R. 62, sec. 26	445	260	2-1		
		445		3	
W. H. Dean, T. 105, R. 62, sec. 35	397		2	4	
Henry Coan, T. 105, R. 59 (southwest corner)	315		2	25	
W. M. Selvert, Butler, T. 3, R. 14	511	506	2	100	
P. Trinen, T. 105, R. 61, sec. 26	354		1		
L. Welch, T. 105, R. 61, sec. 3	361		1		
M. Reeves, T. 105, R. 60, sec. 27	445	435	2	30	

These wells are comprised in two groups, and each group represents relatively accordant features. In the Woonsocket region the town well, mill well, and Hines well all obtain large flows from a depth near 700 feet. The logs given in Pl. LXXIX present some minor differences, but these differences are mainly without bearing on the question of water supply. In Pl. LXXVIII there is given a view of the Woonsocket well forcing a good-sized jet of water high into the air.

In the vicinity of Letcher the water-bearing beds appear to have been brought nearer to the surface by the dip, as shown in section 1, Pl. LXXI. The Letcher, McCurdy, Ryan, and Harris wells obtain large flows, when the relatively small bores are considered. Some of the higher flows reported in the Letcher and McCurdy wells, mainly from the chalk, have been tapped by a number of other borings in the general vicinity and small supplies secured. The logs of three wells around Letcher and of the Coan well are given in Pl. LXXX. They indicate an eastward thinning of the chalk, which is very marked in the Coan well, if this log is to be relied upon. The Coan well appears to draw its large flow from the 300 to 314 foot horizon in the Ryan well, but possibly it is from a lower one. The extension of the lowest waters east of James River has not been tested, so far as I could ascertain. There are several wells east of the river which obtain water supplies from the chalk at depths of from 125 to 167 feet. In this region, however, there are good supplies in the drift above, a source which furnishes water to a very large number of flowing wells. These wells are most numerous about the village of Artesian, where nearly every house has one. The depth averages 100 feet, and the diameters are rarely more than 2 inches. The yields vary remarkably, and it is found that in most



LOGS OF WELLS IN EASTERN PORTION OF SANBORN COUNTY, SOUTH DAKOTA.

cases the amounts are decreasing. This decrease appears to be due mainly to deposition of iron crusts in the pipe, for a new well usually obtains a flow as large as was found originally in the old one. The water is hard, but varies considerably in this respect. Its head is low, but it is sufficient to give flows throughout the region indicated on Pl. LXIX. The nature of the materials penetrated in the wells is indicated in Pl. LXXXI.

The principal water supply appears to lie in gravel and sand at the base of the blue clays. These are underlain by the chalk in the greater part of the area, and it is probable that the water flows from the chalk into the gravels. This would most readily account for the presence and pressure of the water, although the rise of the clays and gravels into the highlands to the northeastward might also account for them. In the general log for the region around the village of Artesian, given in Pl. LXXXI, no indication of chalk appears, but in a well at the creamery at Artesian the chalk was penetrated at a depth of 210 feet and a small flow of water was obtained. In cases where the chalk is very dark or impure it is often reported as clay or shale by the well drillers, and this probably explains why it does not appear in the log given in the figure.

The western limits of this shallow artesian basin of Sanborn County have not been fully ascertained, but the outline shown in Pl. LXIX is not far from the truth.

MINER COUNTY.

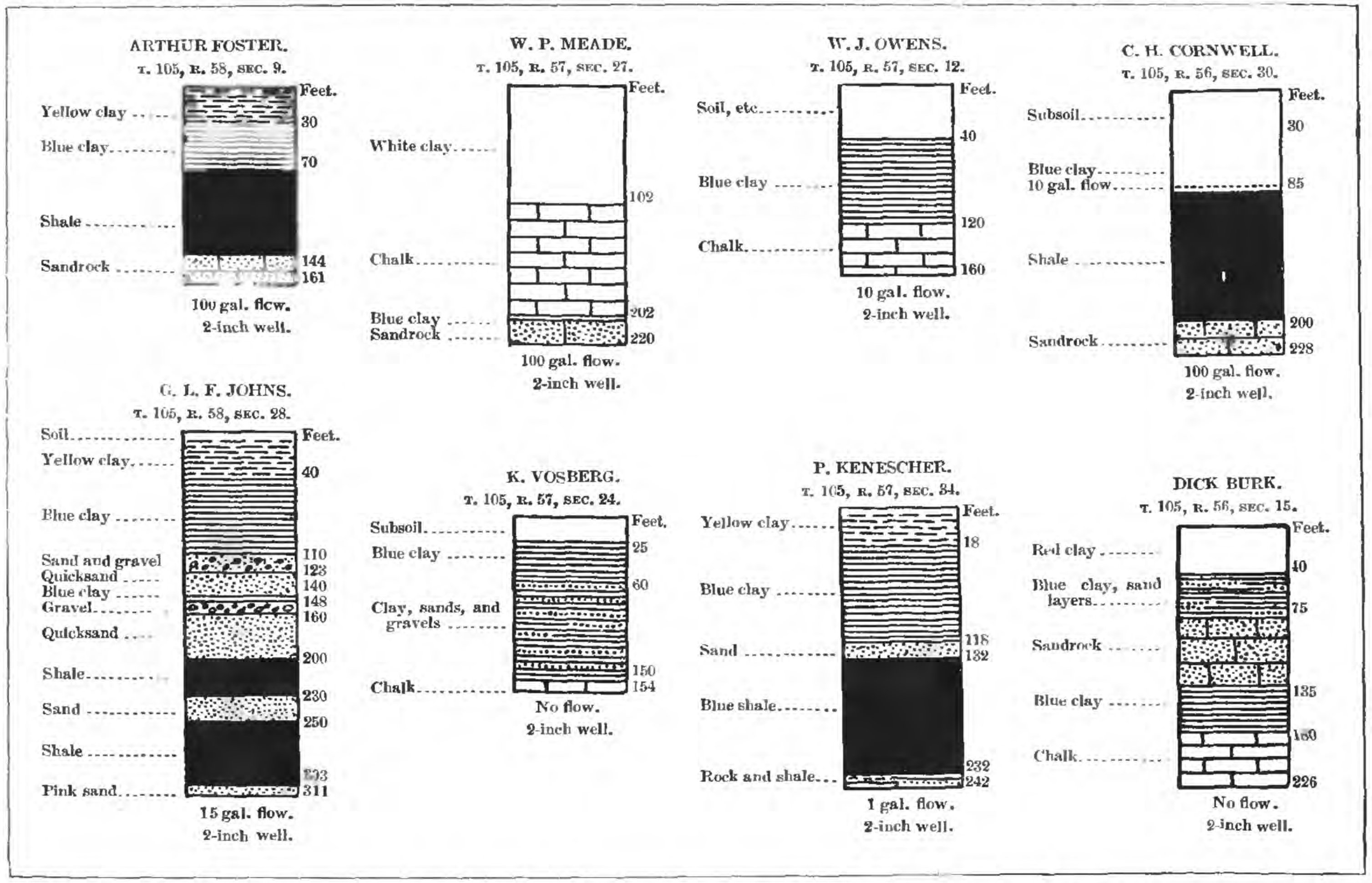
The area of artesian waters at the base of the drift, or in the immediately underlying beds, extends across the western margin of this county, and occupies a district of considerable area lying southwest of Vilas and west of Canova. Its eastern limit is sharply demarked south of Vilas, where the land rises too high for the artesian flows to reach the surface. Its extension north of the Chicago, Milwaukee and St. Paul Railroad has not been explored, so far as I could learn.

No attempts appear to have been made to reach the deeper waters, and I have no data regarding them in this county. Probably they extend some distance into the county from the westward. East of the line of the Northwestern Railroad the land rises rapidly to an elevation too great for artesian flows, and some wells in the northeastern portion of the county have been sunk to depths of 400, 700, and 900 feet without finding satisfactory supplies even for pump wells. In the artesian area in the southwestern corner of the county the wells are very numerous; and although they are usually of small diameter, they yield excellent supplies for general farm use.

A list of wells from which returns have been received is as follows

Partial list of artesian wells in Miner County, S. Dak.

Location etc.	Depth.	Depth to water.	Diameter.	Yield per minute.
	Feet.	*Feet.*	*Inches.*	*Gallons.*
Brigg, J. W., T. 105, R. 58, sec. 26	162	162	2	150
Brown, D. E., T. 105, R. 58, sec. 22	186	186	2	16
Dockstader, H., T. 105, R. 58, sec. 22	144	144	2	75
Foster, Arthur, T. 105, R. 58, sec. 9	161	161	2	100
Hoover, L. D., T. 105, R. 58, sec. 21	170	164	2	100
Pertz, Matt, T. 105, R. 58, sec. 3	108	108	2	Fair.
Henderson, Charles, T. 106, R. 56, sec. 7	126	....	2	90
Arundale, Peter, T. 105, R. 57, sec. 24	150	150	2	70
Cornwell, C. H., T. 105, R. 56, sec. 30	228	86	....	....
		226	2	100
Freeman, P. J., T. 105, R. 56, sec. 20	100	90	2	75
Freeman, F. R., T. 105, R. 56, sec. 19	113	104	2	40
Gosmire, George, T. 105, R. 56, sec. 20	146	125	2	....
Gosmire, George, T. 105, R. 56, sec. 30	97	97	....	100
Gosmire, J. G., T. 105, R. 56, sec. 29	80	....	2	150
Krenscher, P., T. 105, R. 57, sec. 34	242	232	2	1
Krugar, H., T. 105, R. 56, sec. 30	120	94	....	....
		120	2	50
Meade, W. P., T. 105, R. 57, sec. 27	220	....	2	1
Meister, John, T. 105, R. 57, sec. 24	154	135	2	100
Meister, Martin, T. 105, R. 57, sec 27	105	118	1	6
Owens, Owan, T. 105, R. 56, sec. 18	110	110	1¼	2
Patterson, John, T. 105, R. 56, sec. 30	149	109	2	5
Prakle, Lewis, T. 105, R. 56, sec. 32	73	73	2	10
Putman, D., T. 105, R. 56, sec. 18	109	106	2	Much.
Rogers, H. M., T. 105, R. 57, sec. 25	150	148	2	100
Bach, Paul, T. 105, R. 57, sec. 35	184	180	2	18
Curtis, W. V., T. 105, R. 57, sec. 1	150	125	2	Much.
Curtis, W. V., T. 106, R. 56, sec. 31	80	70	2	Much.
Gerhing, C., T. 105, R. 57, sec. 3	55	50	2	2
Larson, N., T. 105, R. 56, sec. 5	90	90	2	25
Mentle, S., T. 105, R. 57, sec. 5	74	74	2	3
Owens, W. J., T. 105, R. 57, sec. 12	160	120	2	10
Tesman, Gus, T. 105, R. 57, sec. 5	78	70	2	45
Briggs, J. W., T. 105, R. 58, sec. 26	162	....	2	200
Brooke, C. E., T. 105, R. 58, sec. 15	170	....	2	4
Brown, D. H., T. 105, R. 57, sec. 19	284	50	2	2
Buck, J., T. 106, R. 57, sec. 20	77	77	2	30
Jones, S., T. 106, R. 57, sec. 30	66	42	2	Much.
Newman, William, T. 106, R. 57, sec. 16	145	9	2	....
Shehan, John, T. 106, R. 57, sec. 20	93	93	2	50



LOGS OF WELLS IN THE SOUTHWESTERN PORTION OF MINER COUNTY, SOUTH DAKOTA.

Partial list of artesian wells in Miner County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.
	Feet.	*Feet.*	*Inches.*	*Gallons.*
Calmus, P., T. 106, R. 57, sec. 23	165		2	50
Christianson, L., T. 106, R. 57, sec. 23	72	60	2	3
Delaney, J. E., T. 106, R. 57, sec. 27	97		2	Much.
Kenney, Thomas, T. 106, R. 57, sec. 26	120	110	2	
Lehner, M., T. 106, R. 57, sec. 26	80	74	2	20
Gey, A., T. 106, R. 57, sec. 15	67	60	3	100
Grey, A. A., T. 106, R. 57, sec. 24	102		2	
Meriam, B. D., T. 106, R. 57, sec. 13	72	68	2	
Meriam, C., sec. 12	192			
Petit, C. F., T. 106, R. 57, sec. 41	90	89	2	8
O'Brien, C., T. 105, R. 57, sec. 35	175	125 175	 2½	 Many.

These wells indicate a relatively uniform distribution of small flows of water in the basal beds of the drift at depths averaging about 100 feet in the artesian area. Some of the wells have had to go deeper for a supply, and the deeper waters have been found to present considerable variability in their occurrence. None of the wells appear to tap the Dakota sandstone horizon, for they have found adequate supplies in the overlying formations. Several logs have been furnished for wells in Miner County, and they are reproduced in Pl. LXXXII.

These logs present considerable diversity, but probably, in two or three cases, this is due in no small degree to mistaken statements of the well borers as to the identity of the materials penetrated. It is claimed that the shallower wells are failing, but in most areas it is found that a new well obtains approximately the original supply. The deeper wells, which draw from beds of sand or chalk under the shale, appear to be increasing in supply. Wells outside of the artesian area are mainly deep, for the shallow ones are unsatisfactory. In the northwestern townships water is scarce at best. A number of wells sunk to great depths have found no water. In a few restricted areas in the northern part of the county a fair supply of water is obtained from sands lying between the yellow and blue clay at from 15 to 25 feet below the surface. In the vicinity of Vilas water is found at the base of the blue clay, often at a depth of about 100 feet. Further northward it lies considerably deeper, but is generally in large amount, and rises to within 25 or 50 feet of the surface.

McCOOK COUNTY.

The area of artesian flows in this county appears to be restricted to the western half of the northwesternmost townships, where, in an area of about 35 miles, there are several small flowing wells. These derive their waters either from the basal drift gravels or the chalk below in an extension of the shallow artesian region of Sanborn County. To the east and south the quartzite rises near to the surface and cuts off the source of supply. The quartzite has not been deeply penetrated by any wells, so that there is still some question in regard to its relations to the deeper waters as is the case in Hanson County.

The following list comprises all the flowing wells in McCook County from which returns were received:

Partial list of artesian wells in McCook County, S. Dak.

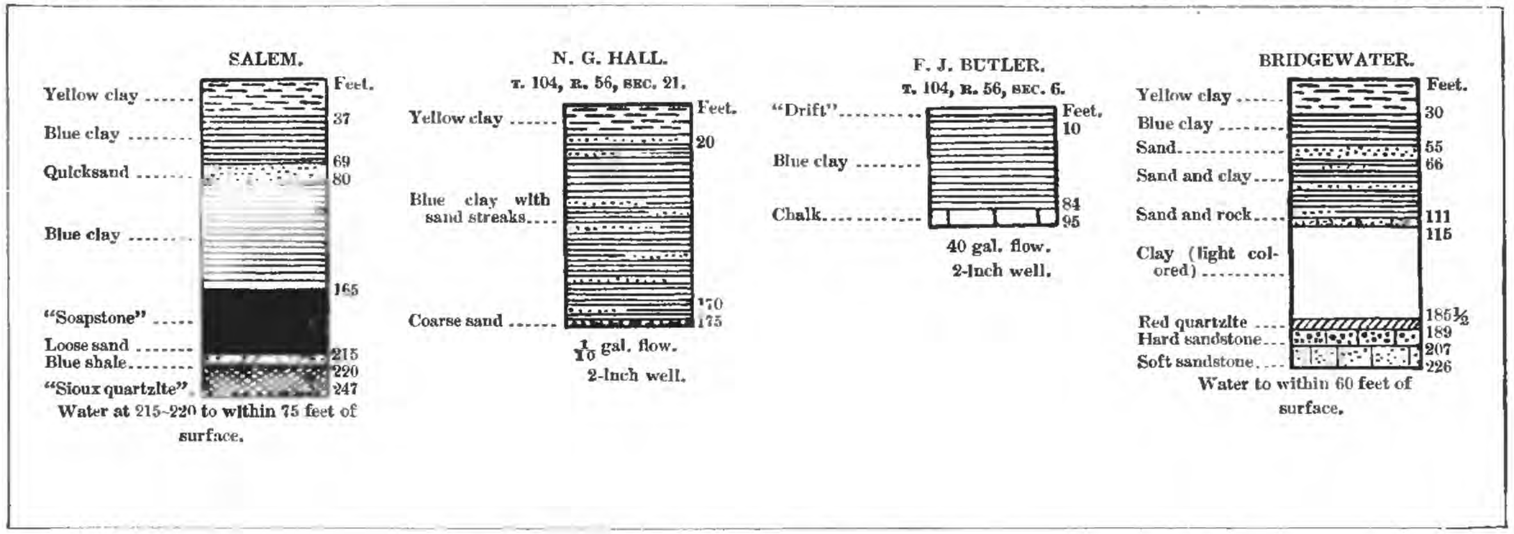
Locations, etc.	Depth.	Yield per minute.	Remarks.
	Feet.	*Gallons.*	
J. N. Dickens, T. 104, R. 56, sec. 8	123	30	In chalk rock
J. F. Gurney, T. 104, R. 56, sec. 17	86	150	
N. G. Hall, T. 104, R. 56, sec. 21	175	$\frac{1}{10}$	
John Madkins, T. 104, R. 56, sec. 30	172	25	
F. J. Butler, T. 104, R. 56, sec. 6	95	40	In chalk rock.

These wells are all 2-inch bore, usually supply hard waters, and the amount of flow is reported to be decreasing.

The quartzite lies only from 100 to 154 feet below the surface about Spencer, and at various depths from 150 to 500 feet or more in the region south and east. At Salem, according to Colonel Nettleton, it was found at a depth of 222 feet and penetrated 25 feet. Water was found in this boring in sand at a depth of 215 to 220 feet which rose to within 75 feet of the surface. At Bridgewater a similar water horizon was found at a depth of 224 feet, but the bottom of the boring at the depth of 229 feet did not reach the quartzite. The logs of these wells and in some other wells of the county are given in Pl. LXXXIII. The Salem log is from Colonel Nettleton's report.

HANSON COUNTY.

The artesian waters in this county have only been developed in the southern tier of townships. The artesian basin at the base of the drift deposits extends into these townships from Sanborn and Miner counties, and its waters furnish moderate supplies to many small shallow wells. There are also several borings, mainly between 500 and 600 feet in depth, which tap sands probably in the Dakota formation, and obtain fairly large flows.



LOGS OF WELLS IN McCOOK COUNTY, SOUTH DAKOTA.

The following list gives all the flowing wells from which returns have been received:

List of artesian wells in Hanson County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.
	Feet.	*Feet.*	*Inches.*	*Gallons.*
M. McDaniel, T. 103, R. 57, sec. 12	200	200	2	40
Phil Doxheimer, T. 103, R. 57, sec. 11	153	153	3	(*a*)
I. S. Shoemaker, T. 104, R. 59, sec. 21	116	116	½	⅙
W. Pattison, T. 104, R. 59, sec. 17	128	125	2	(?)
F. W. Stratton, T. 104, R. 59, sec. 31	155	155	2	6
W. S. Logan, T. 104, R. 59, sec. 17	85	84	2	5
H. P. Hubbard, T. 104, R. 59, sec. 12	246	246	1¼	....
Windsor?, T 104, R. 59, sec. 4	156	....	....	....
G. Thompson, T. 104, R. 59, sec. 11	200	....	2	10
S. P. Jewett, T. 104, R. 59, sec. 7	186	180	2	½
S. Bruner, T. 104, R. 59, sec. 23	97	95	2	*a* 5
G. L. Stratton, T. 104, R. 59, sec. 19	117	117	2	*a* Few.
A. H. Bagley, T. 104, R. 59, sec. 6	180	180	2	*a* 3
G. H. Ball, T. 104, R. 59, sec. 8	124	124	2	....
C. E. Brown, T. 104, R. 59, sec. 8	120	120	2	....
W. Dean, T. 104, R. 59, sec. 19	10	10	2	*a* 1
J. J. Wallace, T. 104, R. 59, sec. 18	170	170	2¼	1
W. D. Knapp, T. 104, R. 58, sec. 24	300	290	2	*a* 1½
C. G. Town, T. 104, R. 58, sec. 1	275	150	3	*a* 6
C. G. Town, T. 104, R. 58, sec. 22	207	....	2	Many.
James Brisbin, T. 104, R. 58, sec. 17	440	315	1¼	*a* Very few.
F. E. Edwards, T. 104, R. 58, sec. 14	528	520	2–1¼	30
E. Foster, T. 104, R. 58, sec. 9	535	....	2	5
G. W. Knapp, T. 104, R. 58, sec. 13	550	530	2	150
T. P. Borrough, T. 104, R. 58, sec. 25	270	270	2	3
Charles Ward, T. 104, R. 58, sec. 23	320	320	2	½
W. W. Foster, T. 104, R. 58, sec. 2	350	350	2	7
William Ozanne, T. 104, R. 57, sec. 8	589	580	2–1¼	50
William Kroeger, T. 104, R. 57, sec. 3	320	....	2	2
Nick Miller, T. 104, R. 57, sec. 22	543	540	2	50
C. L. Holbrook, T. 104, R. 57, sec. 7	212	200	2	*a* ½
Jacob Roth, T. 104, R. 57, sec. 30	365	365	2	*a* 5
Jacob Roth, T. 104, R. 57, sec. 30	235	235	2	*a* ⅛
J. C. Gregory, T. 104, R. 57, sec. 8	600	....	1¼	20
A. C. Nopens, T. 104, R. 57, sec. 12	180	170	2	12
J. Kosat, T. 104, R. 57, sec. 13	175	....	2	....
A. Hines, 7 miles east of Mitchell	356	....	....	....

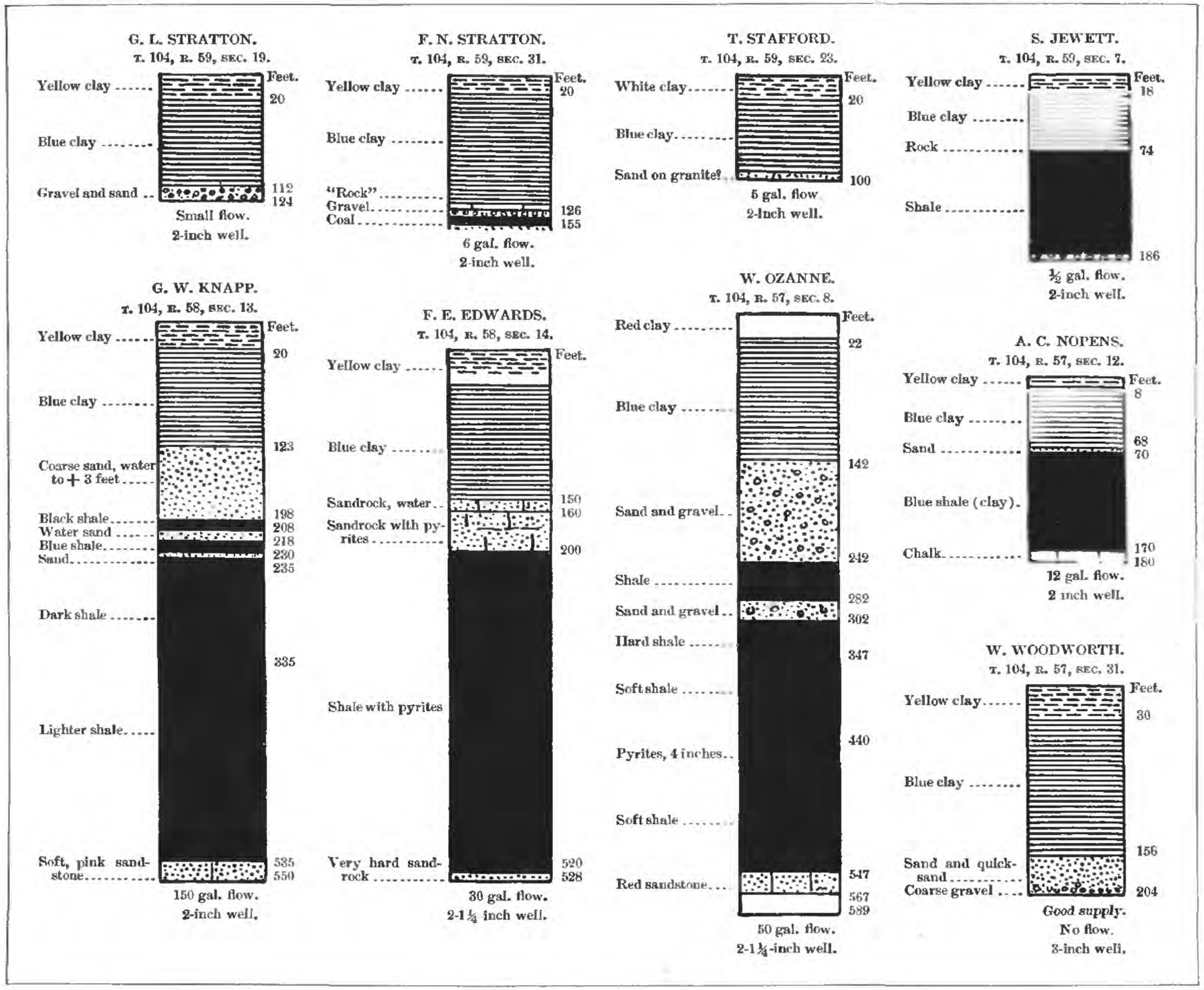
Wells in which the flow is said to be decreasing.

Logs have been obtained of a number of these wells, and they have been represented diagrammatically in Pl. LXXXIV.

These logs indicate a nearly general extension of water-bearing sands and gravel at the base of the drift, and, in the deeper borings, a bed of water-bearing sandstone has been found at depths from 507 to 547 feet. These waters in the drift lie under blue clay, and the deeper-lying sandstones are overlain by dark-colored shales. In the Jewett well the drift gravels are replaced by hardpan, and it was found necessary to penetrate over 100 feet of the underlying shales to obtain a small flow in a thin local bed of sand. This sand bed appears to furnish water to a number of wells in the same township, but in the absence of logs it is not possible to say whether the waters of these moderately deep wells are from basal drift beds or from sands in the underlying shales, as in the Jewett well. The Nopens well draws its waters from the chalk horizon, which furnishes flows in a number of localities in the region northward, but is not reported in other wells in this county. The quartzite begins very abruptly, or rises rapidly, along a line which extends from sec. 12, T. 103, R. 57, to sec. 30, T. 104, R. 59. It has been found in several borings along this line, and it approaches near to the surface southward. It appears to cut off the artesian flow, for no flowing wells have been reported within the area.

In the vicinity of Alexandria, according to Major Coffin, in sinking a well in town they found only sandstone and to a depth of 200 feet observed no traces of quartzite. Water was obtained which rose to within about 30 feet of the surface There is considerable room for question as to whether the quartzite is not a superficial stratum, irregularly hardened and underlain by clays and water-bearing sands. If this is the case, artesian flows may be expected at a depth of 500 or 600 feet. Another view of the quartzite area is that it is an old steep shore against which the Dakota and Pierre beds were deposited. There is not sufficient evidence now in hand to decide the question, and we must wait until some enterprising well borer finally solves the problem by sinking additional borings through the quartzite.

The position of the western edge of the quartzite is not definitely located, but it seems to be quite abrupt, as shown in section 5, Pl. LXXI. A short distance north of Bard there are two wells which appear to lie outside of its area. One is 200 feet deep and the water rises to within 14 feet of the surface; another, belonging to A. Hines, is 350 feet deep, and its water rises to within 20 feet of the surface. Within the quartzite area water is quite plentiful in sands and gravels lying on the rock surface at depths mainly from 20 to 60 feet. In places northeast of Farmer it is somewhat deeper. The deeper the quartzite lies, the greater the quantity of water found above it. In the southern townships of Hanson County plenty of water is usually obtained from 25 to 40 feet below the surface, and over considerable areas these wells do not fail in dry weather.



LOGS OF WELLS IN HANSON COUNTY, SOUTH DAKOTA.

DAVISON COUNTY.

This county lies wholly within the artesian basin, and the waters have been tapped at many localities. The following is a list of wells from which returns have been received:

Partial list of artesian wells in Davison County, S. Dak.

Location, etc.	Depth.	Depths to waters.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
S. S. Pound, T. 102, R. 62, sec. 3.	160	155	4½	....	Under chalk.
John Trotter, jr., T. 103, R. 62, sec. 22.	350	300 350	.... 3½–2½	.... Many.	
Jos. K. Johnson, T. 103, R. 62, sec. 4.	495	300 495	.... 4½	 30	
Charles Arland, T. 103, R. 62, sec. 15.	337	285	4½	32	45 pounds pressure.
Henry Schlund, T. 104, R. 62, sec. 26.	338	240 338	 4–3	.... 450?	92 to 100 pounds pressure.
Jos. Jacobs, T. 104, R. 61, sec. 15.	350	345	2	200	
L. J. Byrne, T. 104, R. 61, sec. 13.	358	....	2	....	
Ira Frazier, T. 104, R. 61, sec. 27.	295	....	3	450	95 pounds pressure.
James Burke, T. 104, R. 61, sec. 12.	410	....	2	40	
G. A. Thomas, T. 104, R. 60, sec. 26.	230	230	2	10	
J. B. Martin, T. 104, R. 60, sec. 17.	400	126 400	....	 100	
Mary Bates, T. 104, R. 60, sec. 23.	260	255	4	2	Flow decreasing.
A. G. Pringle, T. 104, R. 60, sec. 12.	250	250	2	3	Do
W. L. Wallis, T. 104, R. 60, sec. 25.	116	116	2	4	Do.
William Herbert, T. 104, R. 60, sec. 9.	300	275	2	50	
William M. Smith, T. 104, R. 60.	270	200	2	50	
Mike Lawrence, T. 104, R. 60, sec. 7.	400	395	2	21	
Thomas K. Dean, T. 104, R. 60, sec. 26.	288	288	2	1	Under chalk. Flows to + 4 feet.
Nick Gaetz, T. 104, R. 60, sec. 24.	104	103	2	2	
American Investment Co, T. 104, R. 60, sec. 35.	507	350 420	4½–3	40	

Partial list of artesian wells in Davison County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to waters.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
A. L. C. Hillman, T. 104, R. 60, sec. 24.	200	200	2	50	
W. C. Sholes, T. 104, R. 60, sec. 25.	317	267	2	2	
In Mitchell	586	285	....	150	
		445	....	200	
		560	8	250	28 pounds pressure.
Do	548	285	....	....	
		530	....	....	7 pounds pressure.
W. R. Edgington, 13 miles south and 1 mile east of Mount Vernon.	515	500	4½–3½	50	
Oscar Warfield, 12 miles southwest of Mitchell.	433	....	2	20	
H. Schultz, 6 miles northeast of Mitchell.	472	472	2	40	

The logs of a number of these wells are given in Pl. LXXXVII and views of two of the wells are shown in Pls. LXXXV and LXXXVI.

The depth and experiences of these wells indicate considerable variation in the conditions under which the waters occur. The well at Mitchell appears to derive its waters from a horizon low in the Dakota formation, the same no doubt as that at Plankinton, White Lake, and Parkston. The wells in the Mount Vernon region and several of those in the northern tier of townships appear to obtain water from a local sand bed in the clays, considerably above the top of the Dakota sandstone. The area of this higher water appears to be quite extensive, and it yields excellent supplies of water to many wells. In the extreme northeastern portion of the county there is a group of shallow wells which draw either from the horizon just mentioned, brought nearer to the surface by a westerly dip, or from a still higher horizon.

AURORA COUNTY.

This county has been explored for underground waters by wells scattered widely over its area, and there are many wells in adjoining portions of the bordering county, so that there can be no doubt as to the artesian-water resources. All the wells have found large supplies of water; and the pressures, although moderate, owing to the elevated character of the greater part of the county, indicate that all of its area is probably within reach of the flows. Possibly there is a small district in its northwestern corner in which the surface is so elevated that the waters may not have sufficient head to flow with great volume, and along the southern border of the county there is a ridge to which the same suggestion applies; but both of these areas are relatively restricted. The following is a descriptive list of the wells so far as we have been able to obtain data for them:

List of artesian wells in Aurora County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
A. H. Henneaus, T. 103, R. 66, sec. 34	842	650 842	 6	....	
C. R. Cook, T. 103, R. 63, sec. 32	623	520	3–2	15	
A. W. Closson, T. 104, R. 66, sec. 3	922	905	2	75	
S. H. Bullock, T. 104, R. 66, sec. 2	844	710	2	150	
A. D. Dougan, T. 104, R. 63, sec. 21	523	....	4½	150	45
B. H. Sullivan, T. 104, R. 63, sec. 21	525	....	4½	150	
Mullen Bros., T. 105, R. 66, sec. 24	953	....	2	60	
Plankinton	830	540 740	.... 4½–3	 225	91
White Lake	863	790 850	 4	 150	35

The records and experience of wells in this county indicate that the principal water horizon lies in sands just above the quartzite, as shown in section 5, Pl. LXXI. Its attitude is nearly horizontal, or possibly it has a slight inclination toward the north. It appears to be the same horizon as that which furnishes large supplies of water at Chamberlain and in several wells in Douglas County; possibly, also, the deepest waters in the Huron region.

The waters of shallow wells in Aurora County have proved unsatisfactory in quantity during the very dry seasons in nearly all localities. Water seldom occurs under the yellow clay, but in some cases a good supply is obtained under the blue clay. The greater number of wells have to go to greater depths to obtain a satisfactory volume of water.

BRULE COUNTY.

The underground waters in this county have been extensively explored by upward of 24 wells widely scattered over its area. Many of these have been sunk by townships, mainly to furnish supplies for irrigation.

The following is a list of the wells from which we have received returns:

List of artesian wells in Brule County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
County well, T. 101, R. 68, sec. 21.	962	940	8-4½	Many.	
County well, T. 101, R. 68, sec. 12.	937	753 786 851	6	1,098	Water rises 29 inches above well.
A. Steiner, T. 101, R. 69, sec. 5.			3		In progress.
County well, T. 102, R. 71, sec. 2.	1,227	1,225	8	600	
Claus Arp, T. 102, R. 71, sec. 2.	1,230	1,150	8	900	Water rises 6 feet above well.
T. 102, R. 70, sec. 15	1,027	3d flow			
J. M. Greene, T. 102, R. 70, sec. 15.	1,100		6	800	Water rises 14 inches above well.
County well, T. 102, R. 70, sec. 9.	1,165				
L. H. Willrodt, T. 102, R. 70, sec. 21.	1,185	1,041	6	800	
County well, T. 102, R. 68, sec. 16.	1,050	980	6	1,000	
County well, T. 102, R. 67, sec. 18.		890	6		Clogged in part.
D. N. Kaufman, T. 103, R. 71, sec. 12.	1,030	1,000	6	700	In progress.
County well, T. 103, R. 68, sec. 27.	980	850	8		
J. M. Greene, Chamberlain	1,026		6	3,000	
Chamberlain, city well, T. 104, R. 71, sec. 15.	815	716 750 780	6-4	300	529 gallons at first.
County well, T. 105, R. 68, sec. 26.	935	750 825 875	6	815	Water rises 16 inches above well.
County well, T. 105, R. 68, sec. 3.	987	970	6	Many.	Water rises 16 inches above well, 75 pounds pressure.
John Wilkes, T. 105, R. 67, sec. 8.					In progress.
Kimball, town well	1,068		4½	185	20 ponnds pressure.
Ochsner Bros., T. 103, R. 68, sec. 1.	1,065		6	750	20 pounds pressure.

List of artesian wells in Brule County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
County poor farm, T. 104, R. 70, sec. 33.	930	....	6	....	Water rises 26 inches above well.
Mill well, Chamberlain......	600	....	8	Many.	Low ground; 95 pounds pressure; leaks.
Power well, Chamberlain....	685	640	10–8	4,350	110 pounds pressure; 104 at first.

The experiences of these wells indicate an extension of underground waters in the Dakota formation throughout the area of the county. One principal flow is indicated as shown in section 5, Pl. LXXI, which seems to be about midway in the Dakota beds. Some other subordinate flows have been found, but they are insufficient in volume for irrigation purposes. The principal water horizon appears to slope upward to the south, but it is almost horizontal along east and west lines. As the configuration of the county is very uneven, the wells present great variety of depth, as of course those on the highest lands have to go deeper than those at lower altitudes to reach the same bed of water. This is strikingly illustrated about Chamberlain, where the Greene well on the high lands east has a depth of 1,026 feet, the city well 176 feet below has a depth of 815 feet, and the wells at the mills in the lower part of the city are about 600 feet deep, but all draw their supplies from approximately the same bed of water-bearing sands and sandstones. The pressure of the waters in the various wells indicates a sufficient head to furnish flows above the surface level throughout the county, except possibly in a few scattered high points of very small area and in the Bijou Hills, which rise considerably above the reach of artesian flows.

CHARLES MIX COUNTY.

The northwestern portion of this county has been quite thoroughly explored for underground waters, with satisfactory results, and the experience of the wells in adjoining portions of Douglas County eastward has thrown light on the water resources in that direction. The well at Fort Randall and the wells east of Choteau Creek indicate the extension of the waters to the southeastward.

The following is a list of the wells from which reports have been received:

List of deep wells in Charles Mix County, S. Dak.

Location, etc.	Depth.	Depth to flows.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
J. E. C. Wilson, T. 98, R. 68, sec. 13.	1,006	....	6–4	No flow.	
Chris. Singer, T. 98, R. 64, sec. 20.	772	710	....	....	
		772	2	200	52 pounds pressure.
K. O. Hammer, T. 99, R. 69, sec. 19.	966	779	....	....	
		803	....	....	
		838	....	....	
		860	2–1¼	60	50 pounds pressure.
O. Turgeon, T. 100, R. 71, sec. 26.	688	500	....	....	
		614	8	1,700	
Watson Ham, T. 100, R. 71, sec. 29.	785	618	8	500	Water rises 16 inches above mouth of well.
Rhodes Bros., T. 100, R. 71, sec. 18.	868	....	8	2,352	Water rises 42 inches above mouth of well.
W. B. Wood, T. 100, R. 68, sec. 13.	720	....	2–1	....	
J. E. Latham, T. 100, R. 68, sec. 9.	....	760	2	....	Not completed.
J. G. Coates, Chandler	900	....	2	....	Do.
Yankton Agency, Greenwood.	651	420			
		480	....	7	
		552	....	15	
		577	....	30	
		641	6	3,000	

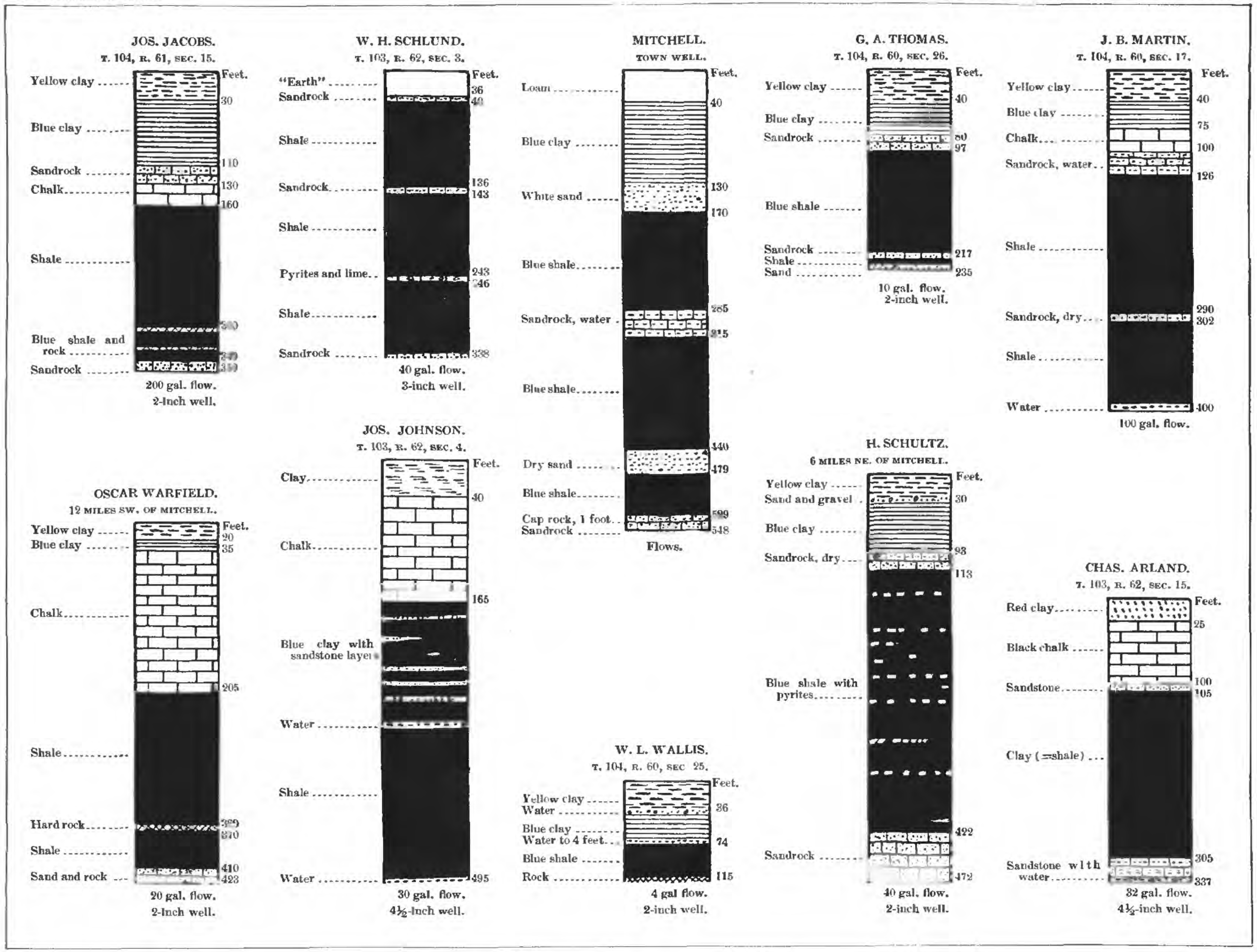
The deeper wells and those in the Missouri bottom appear to draw their water supplies from beds in the Dakota sandstone considerably below its top, and the well near Kirkwood draw from the top beds.

If the Wilson well reached the top of the Dakota sandstone its failure to obtain a flow is probably due to the high altitude of the land on which it was sunk. It is thought that the land is too high for flows on this ridge and its extension and on the ridge in the higher portion of the Yankton Reservation, as shown in Pl. LXIX.

The only well log for western Charles Mix County is that of the Hammer well, as given by Colonel Nettleton. It is shown in fig. 56.

WELL ON FRAZIER FARM, 10 MILES NORTHWEST OF MITCHELL, SOUTH DAKOTA; 295 FEET DEEP, 4-INCH PIPE.

WELL ON SCHLUND FARM, DAVISON COUNTY, SOUTH DAKOTA; 390 FEET DEEP, 4-INCH PIPE.



LOGS OF WELLS IN DAVISON COUNTY, SOUTH DAKOTA.

The following log has been supplied of the well just completed at the Yankton Agency:

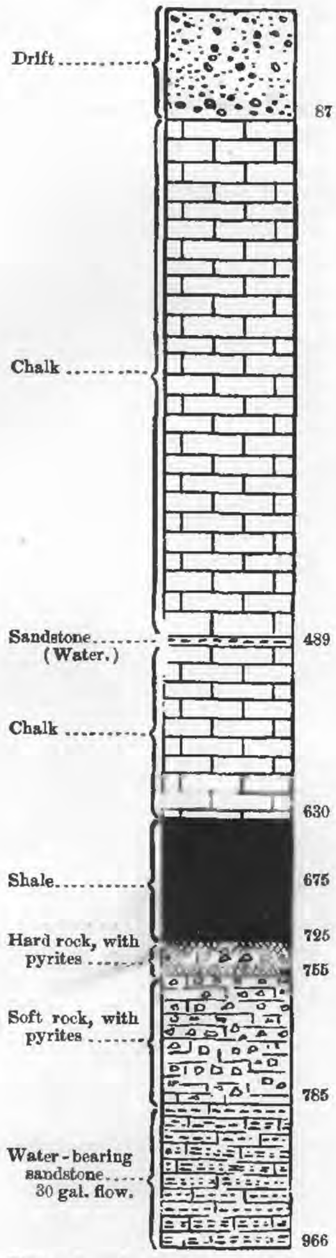


FIG. 56.—Log of A. A. Hammer well, T. 99, R. 69, sec. 19, Charles Mix County, S. Dak.

Feet.	
0–1	soil.
1–25	yellow sandy clay.
25–44	gray shale.
44–75	blue shale.
75–91	blue shale, with chalk and gravel.
91–114	yellow sand and gravel.
114–117	gray rock.
117–123	gray shale.
123–144	gray limestone and pyrites.
144–178	sandy shale and sand.
144–150	much water, which rises to —65 feet.
178–199	blue shale.
199–275	black shale, with pyrites and shells.
275–380	blue shale, tough.
380–420	black shale, with pyrites and shells.
420–421	sand, with flow of 10 gallons per hour, 56° F.
421–448	brown shale, with streaks of sand, and lime rock.
448–497	black shale, with thin sandy streak, and 7 gallons per minute flow at 482–495 feet; soft water.
497–500	gray shale.
500–531	black shale, with lime and pyrite streaks.
531–552	gray shale.
552–556	sand rock, third flow, 15 gallons per minute.
556–577	gray shale.
577–579	sand rock, fourth flow, 30 gallons per minute, soft water.
579–641	gray shale full of lime and pyrite streaks 2 to 12 inches thick.
641–651	sand rock, very soft, 3,000-gallon flow, hard water, 70° F.

DOUGLAS COUNTY.

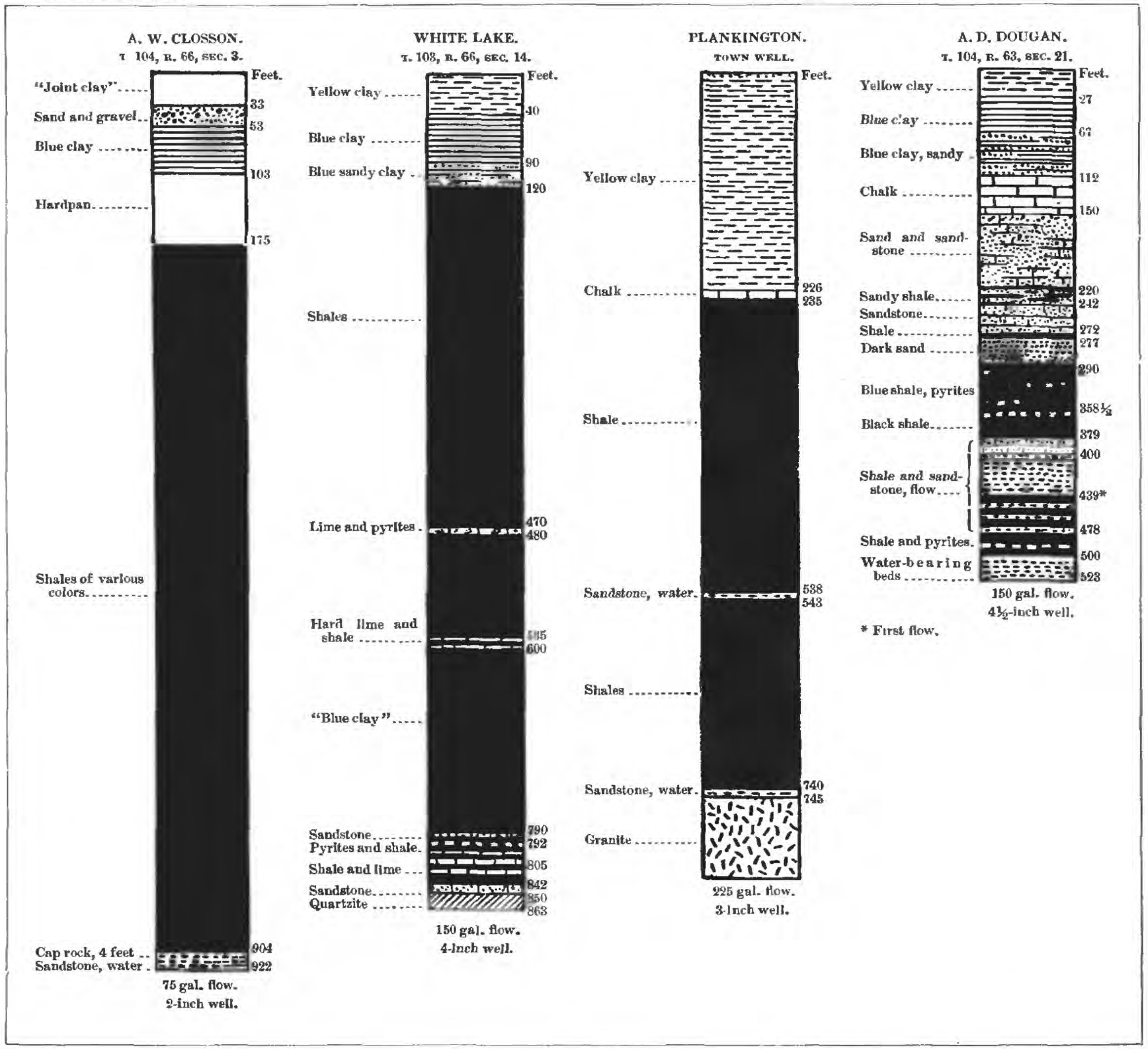
The wells in Douglas County are quite numerous, and they are so scattered over the area as to indicate the probable extension of the artesian waters throughout the county. It is possible that in the extreme northwestern corner of the county the land is too high for an artesian flow, but this area, if it exists at all, is very restricted in extent. The wells from which we have received returns in Douglas County are given in the list on the following page, which is thought to be very nearly complete.

List of artesian wells in Douglas County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
C. O. Knapp, T. 98, R. 65, sec. 2	860	760	6	900	
L. W. Wheelock, T. 98, R. 64, sec. 2	901	753			
		787	8-6		
		842		650	
County well, T. 99, R. 65, sec. 14	925		4	600-700	
F. E. Van Zee, T. 99, R. 65	1,010	969	6	1,000	
J. A. Wilson, T. 99, R. 63, sec. 35	703½	614			
		682			
		703	8-6	2,100	75
Ernest Bertram, T. 100, R. 62, sec. 16	600		2	Many.	
County well, T. 100, R. 62, sec. 18	1,025	800		Few.	
		1,025		1,025	
County well, T. 100, R. 63, sec. 15	750		4	600-700	
County well, T. 100, R. 64, sec. 26	937	820	6	900	40
County well, T. 100, R. 64, sec. 26	975	975	4	1,000	
J. Markin, T. 100, R. 65, sec. 9	80	70	12	Little.	
Armour Mill Company, in Armour	800		8	1,500	
City of Armour	757	720	6	1,500	55
Delmont	821		2	60	
Fleusburg	611		2	60	
Flensburg, half a mile west	651		2		
Flensburg, three-fourths of a mile southwest.	775		2	65-70	

These wells appear to draw their water supplies from two horizons, which seem to be quite constant over a wide area. Some of their relations are shown in section 6, Pl. LXXI. The deeper wells around Armour, at Delmont, and in the northeastern corner of the county draw from the lower horizon. The deeper wells in the northwestern portion of the county probably draw from the higher horizon, and their greater depth is due to the increased height of the land. The water-bearing beds appear to lie almost horizontal, or with a slight slope toward the north. The logs of a number of Douglas County wells are illustrated in Pl. XC.

Only a small amount of information has been gathered regarding the nonartesian waters of this county. Many farmers depend for their water supplies on shallow wells, 10 to 40 feet in depth, but the water in these is often inferior in quality and in most cases gives out in dry weather. Along the larger depressions, notably along Choteau Creek, moderately large volumes of water are found at about 20 feet below the surface, and many farmers in adjacent higher lands haul



LOGS OF WELLS IN AURORA COUNTY, SOUTH DAKOTA.

their water supplies from wells in these depressions. In the northwestern corner of the county considerable water is found at depths of from 350 to 400 feet in sand under alternations of chalk, rock, and shale. In the northeastern portion of the county water is found at depths of from 200 to 260 feet, which comes to within about 150 feet of the surface, and this condition prevails along nearly all the eastern side of the county, where there are many pump wells about 225 feet in depth. In the central portion of the county water is often found in sands lying under the yellow clay, and almost always in good supplies in sands and gravels underlying the blue clay at depths of from 75 to 150 feet at most localities.

HUTCHINSON COUNTY.

Artesian waters appear to occupy only the portions of this county lying west of Dakota River and a narrow belt adjoining the river on the east and extending north and east of Menno. I have not heard of any deep wells in the northeastern and eastern portions of the county, so that I can not make a positive statement in regard to the prospects for water in that section. There are a great many flowing wells in Hutchinson County, but returns or information have been received only for the following ones:

Partial list of artesian wells in Hutchinson County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
Frederick Heiboldt, T. 97, R. 57, sec. 11.	154	135	2	10	Flow decreasing.
Jacob Gundert, T. 97, R. 57, sec. 21.	747	630	2	6	Do.
Johannas Weber, T. 97, R. 56, sec. 18.	122	122	4	27	
William Tarl, T. 98, R. 61..	482	....	....	60	
F. A. Morris, T. 98, R. 60, sec. 21.	559	531	2	50	Flow increasing.
John Tiede, T. 98, R. 61, sec. 1.	130	....	....	....	
H. Dewald, T. 98, R. 56, sec. 17.	54	53	3		
Mrs. Pope, T. 99, R. 61, sec. 14.	140	140	6	....	
M. Heizinger, T. 99, R. 60, sec. 7.	527	....	2	150	
Parkston	542	472	3	30	
3 wells 4 miles north of Tripp.	540	....	2	9	
	577	....	....	....	
	580	....	....	....	

Partial list of artesian wells in Hutchinson County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
4½ miles east of Parkston	130		3	Many.	
Menno	417		6	(*a*)	
Northwest corner of county	560			10	
1 mile southwest of Parkston.	515			50	
Tripp	815		6	700	Pressure 9 pounds; flow decreasing.

a One-fourth of an inch stream.

These wells indicate that in the western part of the county there is an extensive water horizon lying at a depth of about 550 feet below the surface, and apparently nearly horizontal in position. It is claimed that the Sioux quartzite was found just below this water horizon at Parkston, which would indicate the relations shown in section 1, Pl. LXXI, and which is further borne out by the experience of the well at Scotland, as shown in section 6 on the same plate. The well at Tripp is on a relatively high ridge, to which the increased depth and decreased pressure of the waters are due. The experience of the wells around Menno is exceedingly variable, but owing to lack of data as to the materials penetrated no definite suggestions can be offered as to the horizon of the waters. The Gundert well, having a depth of 747 feet, indicates that the quartzite dips more steeply to the south than would be expected from the experience of the Menno well. A few logs of wells in Hutchinson County are illustrated in Pl. XCI.

At several points in the southeastern portion of the State small flows of hard water are obtained in shallow wells, apparently from the lower portion of the drift.

TURNER COUNTY.

This county appears to lie entirely outside of the area in which artesian flows from the Dakota formation may be expected. It has, however, a local artesian basin of its own, which extends along the valley of Turkey Ridge Creek. The wells are quite numerous, and although mainly of small size—2 inches—they furnish satisfactory supplies to many farmers. Their depths vary mainly from 40 to 75 feet, but a few are shallower and several are deeper. The water is hard, but there is considerable variability in the degree of hardness. The volume of water is also very variable, but a large number of the wells furnish from 5 to 10 gallons per minute. A few furnish considerably more than this. The water supply appears to lie in gravels and sands at the base of the blue clay of the drift formation, in a relation somewhat similar to that in the Artesian City region of Sanborn County. The source of water and pressure is probably from the underlying chalk beds, but possibly from the higher lands adjoining the valley. Features of some of the wells are given in the following list:

Partial list of artesian wells in Turner County, S. Dak.

Location, etc.	Depth.	Diameter.	Yield per minute.
	Feet.	*Inches.*	*Gallons.*
C. S. Goodhope, T. 97, R. 53	62	2	(*a*)
L. P. Flyger, T. 97, R. 53, sec. 18	60	2	*a* 15
P. J. Farrar, T. 97, R. 53, secs. 13 and 18	85	2	*a* 5
Fred Snyder, T. 98, R. 54, sec. 33	50	2	*a* 8
Joseph Andrews, T. 97, R. 54	50	2	*a* 5
T. B. Buchanan, T. 97, R. 54, sec. 12	110	2	350
A. Denoma, T. 96, R. 52, sec. 35	52	2	*a* ⅛
Lars Peterson, T. 97, R. 54, sec. 2	37	2	3
Fred Fields, T. 97, R. 52, sec. 2	59	18	....
E. J. Thompson, T. 97, R. 54, sec. 11	59	2½	*a* 4
A. A. Powers, T. 97, R. 54, sec. 4	40	2	....
E. P. Moore, Swan Lake	50	2	40

a Flows decreasing.

Outside of the artesian area in this county, water is found in greater or less abundance in wells from 45 to 160 feet in depth, ordinarily at the base of the blue clay. Some wells have found no water in this horizon, due mainly to the absence of coarse material, and have penetrated to sandy streaks in the underlying shales. One well, 5 miles west of Hurley, is stated to have gone to a depth of 513 feet and found a fair supply of water, which rises to within 72 feet of the surface. It is reported that in the northeastern corner of the county the Sioux Falls quartzite is found at a depth of from 90 to 115 feet, and the sands which overlie it usually contain a moderately large amount of water. In some cases chalk stone lies directly on the quartzite, and the more porous portions contain considerable water. In the central and eastern portion of the county, wells are usually sunk to from 75 to 225 feet for water, which rises to within 20 to 100 feet from the level of the ground. In the western part of the county, water is often found at from 100 to 200 feet, but is more certain to be found in sands in the slate at a depth of from 350 to 500 feet. Logs of some wells, mainly nonflowing, are given in Pl. XCII.

BONHOMME COUNTY.

This county appears to lie almost wholly within the artesian area, but its wells have met with a considerable variety of experience. They have all been successful in obtaining flows of satisfactory water, so far as we have heard, but in some instances the volumes have not been very great. The following list will indicate the principal features of all the deeper wells from which reports have been received:

List of artesian wells in Bonhomme County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
Peter Byrne, T. 93, R. 58, sec. 5	660	600	3	95	45
Allois J. Zienert, T. 95, R. 59, sec. 34	730	700	2	*a* 97	35
James P. Cooley, T. 94, R. 58, sec. 19	576	512	3	11	....
Alfred J. Abbott, T. 93, R. 59, sec. 1	646	460 480 580	.... 1	.... 30	.... 62 ....
Lewis Schneider, T. 94, R. 58, sec. 32	640	....	2	75	....
Scotland, new well	590	....	6	....	....
Scotland, old well	587	512	....	9	....
City of Tyndall	736	....	4½	1,000	30
Tyndall mill	752	....	8	....	40
Springfield, well at mill	592	440 530	 8	 3,292	 86
Springfield, town well	....	....	4	....	....
H. P. Layson, T. 94, R. 61, sec. 22	1,074⅜	822 1,042	.... 3–2½	.... ⅓	.... 2½
Skakal & Hardwick, mouth of Choteau Creek	837	....	....	1,700	62
Charles Dehlenberg, mouth of Choteau Creek	897	....	6	1,200	62

a Decreased to 50.

The well at Springfield is a phenomenal one, with its flow of 3,292 gallons per minute, although its closed pressure is not so great as that of many other wells in the State. It furnishes power for a 60-barrel flour mill by day and an electric-light plant by night. At one time it threw sand for a while, and when this finally ceased the flow was thought to have slightly decreased. When the city well was finished it was allowed to run at full head for some time, and it was then observed that the flow of the mill well was noticeably weakened for the time being. A view of the mill well is reproduced as fig. 57.

The well at the mill at Tyndall clogged up some time ago, but it was recently cleaned out and the former flow and pressure regained.

The first well at Scotland was sunk to a depth of 582 feet, of which the last 52 feet were into quartzite. The water supply found in sand on the surface of this quartzite was so small that the well was regarded as a practical failure. Recently another boring was sunk not far from the old one, and it passed through the hard bed into clear, white sand at 590 feet, but obtained no increase in flow. The Layson well was sunk on the high ridge lying between Emanuel Creek and Choteau Creek to a depth of 1,074 feet and 8 inches. Only a feeble flow was found, and the pressure was sufficient to raise the water only to about 7 feet above the surface. The wells at Tyndall, those in the southeastern corner of the county, and those in the Missouri bottom near the mouth of Choteau Creek yield more satisfactory supplies. The

FIG. 57.—Artesian well at mill in Springfield, S. Dak.

artesian waters in Bonhomme County all appear to come from approximately the same horizon excepting those at Scotland, Layson, and the mouth of Choteau Creek. At Scotland the waters appear to be largely cut off by a ridge of the quartzite bed rock, as shown in sections 1 and 6, Pl. LXXI. The Layson well appears to have been sunk to a horizon considerably below that of the group of successful wells to the east and south. The low pressure at the surface is due to the height of the land on which the well is sunk, and the small volume of water is no doubt due to some variation in texture, such as occasionally occurs in the Dakota beds. The wells at the mouth of Choteau Creek appear to draw their waters from a horizon somewhat lower than that at Springfield and Tyndall. Probably it is the same horizon as that which furnishes the small flow at the Layson well on the ridge northeast, but here of such a character as to furnish a larger volume of water.

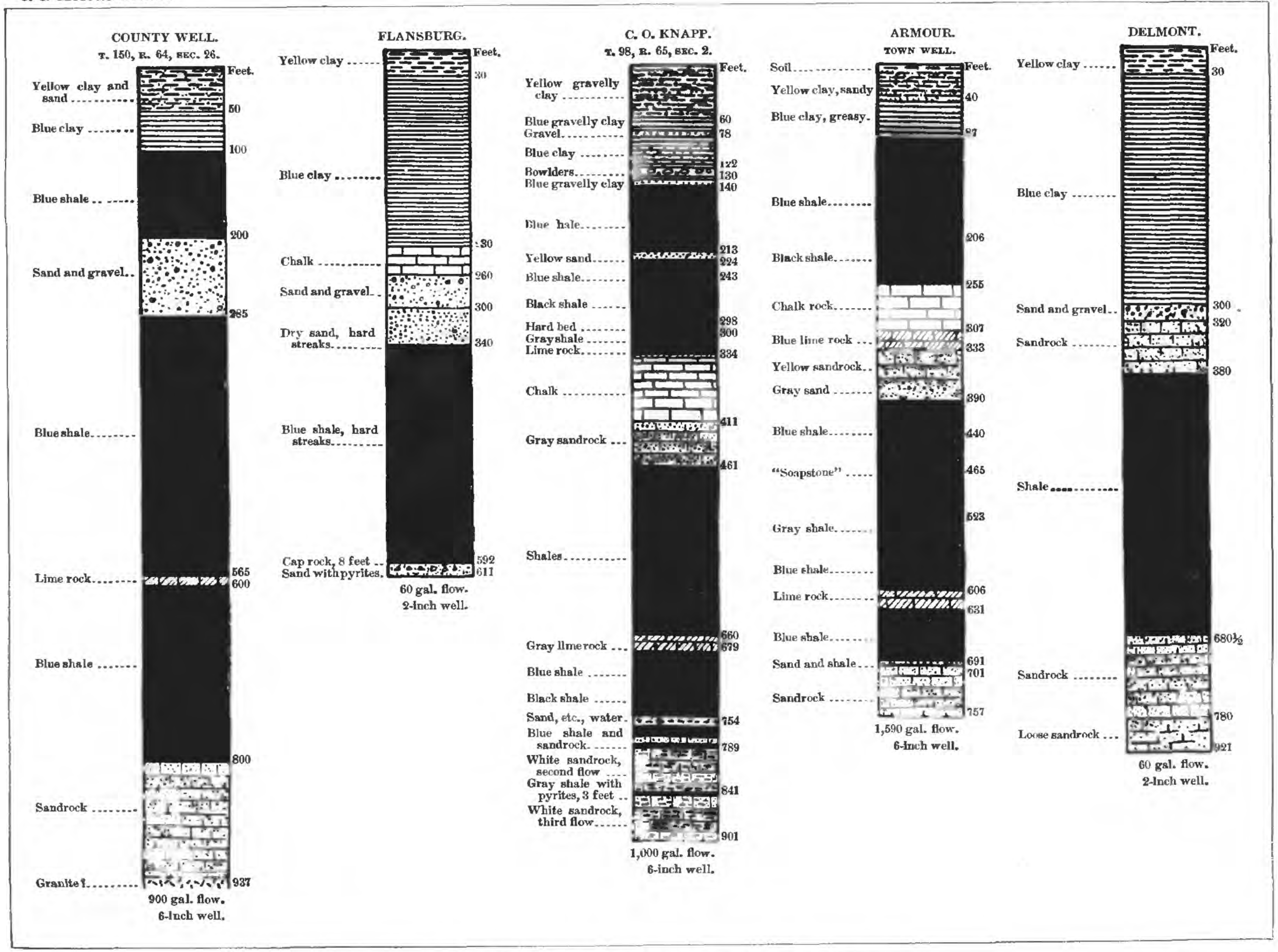
Logs of a number of Bonhomme County wells are given in Pl. XCIII.

The head of the waters in Bonhomme County is considerably less than it is northward, for the amount decreases rapidly to the south and east in this region. It appears, however, to be sufficient to bring waters to the surface over all of the county, probably excepting the high ridge between Emanuel Creek and Choteau Creek.

In the nonflowing waters in the county there is considerable variation. Many farmers depend upon wells from 10 to 40 feet deep which draw their supplies from sands under the yellow clay. These wells usually fail in dry seasons. At depths of from 100 to 140 feet sands and gravels are generally found under the blue clay, containing water which often rises to within from 6 to 40 feet of the surface, and in most cases does not fail. At certain localities, which at present we can not delimit, the water is absent at this horizon. Sometimes in such cases water is found in sandy beds in the shale below, but these often lie quite deep. At Scotland water is often found at about 50 to 60 feet below the surface in chalk rock, but the occurrence is quite variable. East of the village the water underlies an irregular area of considerable size at a depth of 30 feet, but at the depot no water was obtained at a depth of 160 feet. On the fair grounds a moderate supply is yielded by a well 125 feet deep, in which it is stated that an 18-inch chunk of wood was penetrated at 100 feet. North of Scotland there are several wells which obtain water at depths of from 100 to 125 feet.

YANKTON COUNTY.

The artesian waters are extensively developed by many wells in the southern portion of this county. In and about the city of Yankton there are about a score of wells, and along the Missouri and James bottoms there are many others. Owing to the upward pitch of the formations to the southward the water-bearing beds lie at very moderate depths in the lowlands in this county, so that the lessened expense of bringing the waters to the surface has made them serviceable to a large number of persons.



LOGS OF WELLS IN DOUGLAS COUNTY, SOUTH DAKOTA.

The following is a list of the wells so far as we have been able to obtain returns from them:

Partial list of artesian wells in Yankton County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
Yankton:		300	....	....	
Excelsior Mill	493	375	....	....	
		450	8	[a]3,000	52 pounds pressure.
Fountain Roller Mills	600	500	6	[a]1,500	48 pounds pressure.
Asylum	672	600	4½	165	10 pounds pressure.
City well	615	610	6	880	18 pounds pressure.
College Hill	524	....	2	2,600	27 pounds pressure.
E. P. Wilcox	455	422	3	330	55 pounds pressure.
Fred. Donaldson	525	175	....	....	
		525	4½	....	Irony water.
F. A. Smith, T. 93, R. 56, sec. 12.	475	....	2	[a]6	
J. A. Pierson, T. 93, R. 56, sec. 17.	400	....	2	50	
Cement Co., T. 93, R. 56, sec. 16.	500	375	....	....	
		390	....	....	
		405	....	....	
		433	....	....	
		450	6-5	1,300	50 pounds pressure.
G. H. Whiting, nursery, T. 93, R. 55, sec. 8.	521	....	3	350	49 pounds pressure.
W. H. Semple, T. 93, R. 55, sec. 2.	392	....	1	50	
T. Nelson, T. 93, R. 55, sec. 27.	365	....	2	[a]2	
Ed. Anderson, T. 93, R. 54, sec. 13.	250	225	2	[a]50	
S. Cross, T. 93, R. 54, sec. 2	300	250	....	....	
		300	2	[a]10	
Mat Larson, T. 93, R. 54, sec. 8.	290	260	2	60	
P. N. Lund, T. 93, R. 54, sec. 25.	271	....	2	[a]6	
A. Peterson, T. 93, R. 54, sec. 11.	450	435	2	80	
T. Inch, T. 93, R. 54, sec. 9	265	265	2	[a]50	
A. L. Van Osdel, T. 93, R. 54, sec. 18.	422	246	....	....	
		420	3½-3	[a]120	

[a] Flow decreasing.

Partial list of artesian wells in Yankton County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
William Warfield, T. 93, R. 54, sec. 26.	255		2	20	10 pounds pressure.
Peter Birgs, T. 94, R. 55, sec. 18.	480		2	55	
A. Simonson, T. 94, R. 55, sec. 22.	522	400 522	 2	 *a* 30	
F. Schafer, T. 94, R. 55, sec. 19.	648	635	4½–2	*a* 4	Alkaline water.
H. Strunk, T. 94, R. 55, sec. 21.	435	425	2	*a* 100	
G. H. Brown, T. 94, R. 54, sec. 30.	125		2		
M. Bagslad, T. 94, R. 54, sec. 29.	315	300 315	 2	 *a* 5	
S. Bruget, T. 94, R. 54, sec. 20.	300	230 300	 2	 *a* 15	Irony water.
P. J. Conkling, T. 94, R. 54, sec. 36.	495	490	2	*a* 75	
Arch. Douglas, T. 94, R. 54, sec. 27.	300	250 300	 2	 *a* 30	
C. J. Freng, T. 94, R. 54, sec. 28.	378	290 370	 1½	 25	Irony water.
Jacob Hanson, T. 94, R. 54, sec. 30.	363	363	2	*a* 12	
Larse Hanson, T. 94, R. 54, sec. 19.	312		2	*a* 10	
F. P. Hardin, T. 94, R. 54, sec. 31.	280		2	20	
J. Turitti, T. 94, R. 54, sec. 34.	385	300 385	 2–1½	 *a* 15	
Frank Hefner, T. 95, R. 55, sec. 8.	535		2	*a* 50	

a Flow decreasing.

The experience of these wells indicates the existence of several flows of water, of which there is more or less local variation in volume. The deeper-seated waters are most uniform in this respect and furnish large supplies, mainly in Yankton and its vicinity. The higher horizons furnish water for many small wells for local farm use, which were sunk only sufficiently deep to reach a moderate supply. In Yankton the waters are used to a considerable extent for power in mills and for the usual municipal demands. Those on the higher lands are considerably over 600 feet in depth, while those far down in the bottom have a proportionally less depth. The variations in pressure are due mainly to differences in altitudes of the wells, but there is a gradual decrease to the eastward. The mill well in Yankton has been furnishing power for several years with most satisfactory results. For a considerable period it was allowed to flow all the time, and finally was found to be losing pressure. The practice was then inaugurated of shutting off the flow when the mill was not running, and since then the pressure has remained constant at 37 pounds. Originally it was 45 pounds. Probably the diminution is due to caving below. At the Excelsior Flouring Mill, where a well has been in use continuously for power for three years, the pressure appears to be gradually failing, but it is claimed that the loss of pressure is due to escape of the water. The Insane Asylum well appears to have lost pressure since 1887.

It appears from the experience of the wells, and from the pressures which they develop, that artesian flows are not to be had in the elevated region northeast of the valley of James River, except locally in the deeper parts of some of the depressions. To the west and south and throughout the Missouri bottom abundant supplies of flowing waters may be expected, unless possibly on one or two small areas of higher elevation along the western border of the county.

Logs of a number of wells in Yankton County are reproduced in Pl. XCIV.

CLAY COUNTY.

In the lower lands of this county artesian waters have been tapped at many localities. The rise of the water-bearing beds to the southeastward and the decrease in altitude of the lower-lying lands bring the waters near to the surface in this region. The greater number of wells average about 300 feet in depth, and some do not greatly exceed 200 feet. There are several horizons of waters, and the lower ones usually yield the largest flows and have the highest pressures. In the deeper wells the higher water horizons were passed through, although in the returns which we have received they are not noted in every case. In section 6, Pl. LXXI, the relations of some of these water horizons are indicated. The wells are mainly in the wide bottom of the Missouri River, but there are quite a number in the bottoms of the Vermilion and its branches. The greater number of these wells are given in the following list:

Partial list of artesian wells in Clay County, S. Dak.

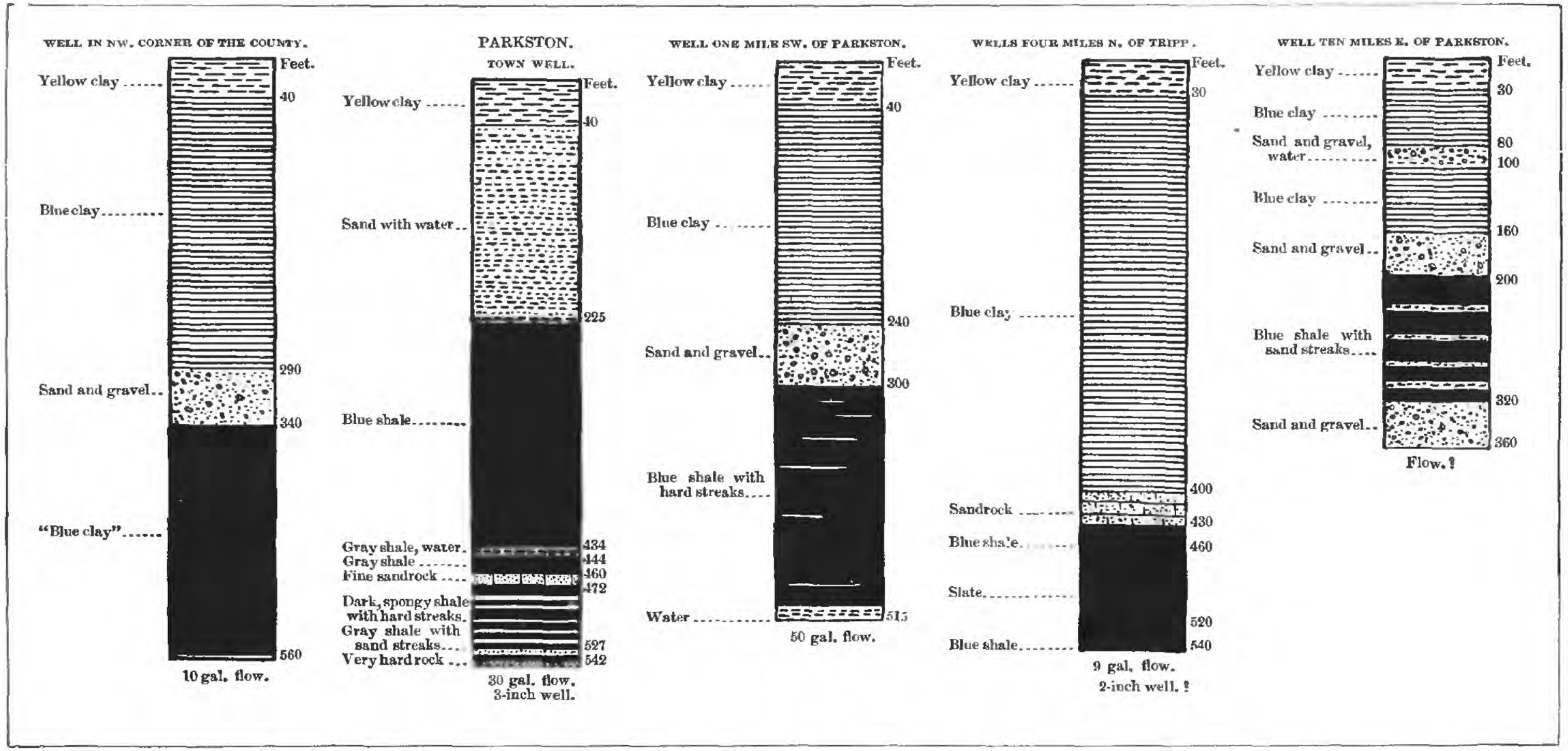
Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
G. W. Richardson, T. 95, R. 52, sec. 32.	260	......	2	1	Alkaline; rises 20 feet above surface.
A. Newton, T. 95, R. 52, sec. 9	500	480	3-2	[a]3	Soft water.
C. A. Loomis, T. 95, R. 52, sec. 29	273	250	2	4	
Barton & Son, T. 95, R. 52, sec. 22.	360	240	......	....	
		360	2	[a]2	

[a] Flow decreasing.

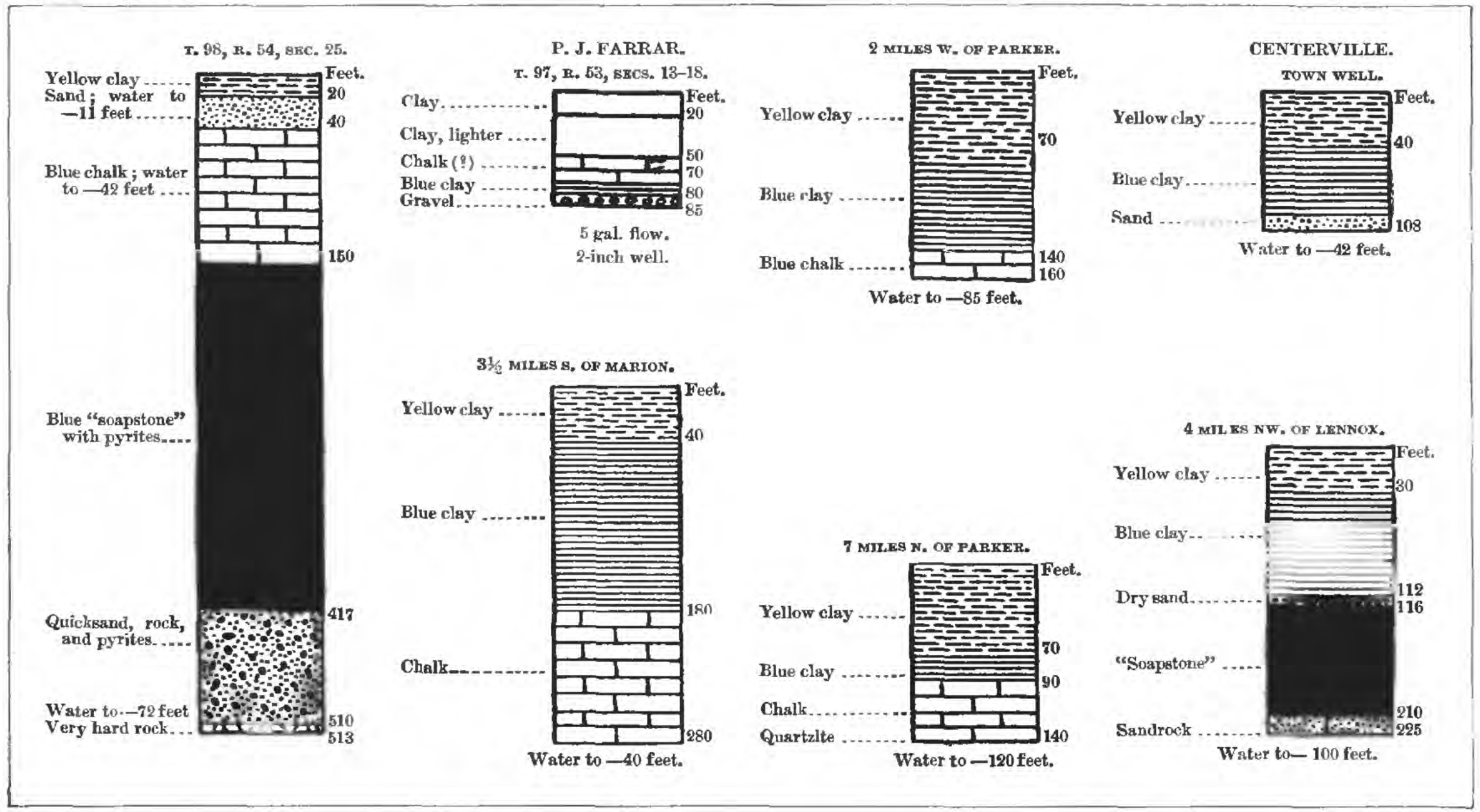
Partial list of artesian wells in Clay County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
H. Grangaard, T. 94, R. 52, sec. 11	402	250	......	....	
		400	2	[a]5	
J. M. Nellis, T. 94, R. 52, sec. 15	400	......	1¼	[a]Many.	
H. Buckman, T. 94, R. 53, sec. 31	260	240	......	....	
		260	2	(*a*)	Soft water.
J. H. Millage, T. 94, R. 53, sec. 8	285	......	......	....	
A. Jackson, T. 94, R. 53, sec. 33	500	240	......	....	
		500	2	[a]Few.	Irony water.
J. E. Fisher, T. 93, R. 51, sec. 29	400	......	1¼	[a]3	
J. Harrington, T. 93, R. 51, sec. 31	410	......	1	[a]1	
J. Harrington, jr., T. 93, R. 51, sec. 20.	334	180	......	....	
		334	2	[a]20	
P. W. Peterson, T. 93, R. 51, sec. 19	315	305	2	[a]5	
W. M. Parks, T. 93, R. 51, sec. 30	350	310	3–2	[a]9	
S. Ellingsen, T. 93, R. 52, sec. 22	325	280	2	[a]5	
H. R. Edgerton, T. 93, R. 52, sec. 2	294	100	......	....	
		290	2	[a]6	
Nels Nelson, T. 93, R. 52, sec. 21	281	......	2	[a]15	
A. T. Olson, T. 93, R. 52, sec. 34	328	260	2	[a]4	
C. Olson, T. 93, R. 52, sec. 22	356	280	......	....	
		350	2	[a]20	
George Woodworth, T. 93, R. 52, sec. 16.	315	290	3–2	....	
D. S. Good, T. 93, R. 53, sec. 16	270	240	2	60	
James Fargo, T. 93, R. 53, sec. 31	310	246	......	....	
		310	2	[a]60	
Wm. Elliot, T. 93, R. 53, sec. 25	340	308	1	....	
B. Bottleson, T. 93, R. 53, sec. 35	240	......	2	[a]1½	
G. W. Gilbert, T. 93, R. 53, sec. 28	351	......	2	[a]150	40 pounds pressure.
M. L. Mikkelson, T. 93, R. 53, sec. 34.	295	199	2	[a]30	
E. Erickson, T. 93, R. 53, sec. 29	306	......	2	(*a*)	Alkaline water.
M. A. McElvain, T. 93, R. 53, sec. 7	304	......	2	(*a*)	
C. Miller, T. 93, R. 53, sec. 27	270	195	2	[a]30	
M. Odland, T. 93, R. 53, sec. 32	367	220	2	[a]75	
S. Olson, T. 93, R. 53, sec. 7	275	......	2	(*a*)	
O. Olson, jr., T. 93, R. 53, sec. 35	350	......	2	10	
J. Olson, T. 93, R. 53, sec. 34	275	225	2	20	
O. Odland, T. 93, R. 53, sec. 18	343	240	2	60	
H. W. Peterson, T. 93, R. 53, sec. 28.	310	255	2	[a]15	
N. Peterson, T. 93, R. 53, sec. 33	290	250	2	8	
C. N. Taylor, T. 93, R. 53, sec. 16	320	......	2	....	

[a] Flow decreasing.



LOGS OF WELLS IN HUTCHINSON COUNTY, SOUTH DAKOTA.



LOGS OF WELLS IN TURNER COUNTY. SOUTH DAKOTA.

Partial list of artesian wells in Clay County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
K. Halverson, T. 93, R. 53, sec. 20	240	120	2	6	
A. M. Edgerton, T. 93. R. 53, sec. 35	340	240 340	 2	...... *a* 50	
N. A. Anderson, T. 92, R. 51, sec. 33	400	350	3–2	(*a*)	
K. Olson, T. 92, R. 51, sec. 28	365	239	2	*a* 90	Soft water.
T. S. Stanley, T. 92, R. 52, sec. 13	366	335	4½–3	30	
B. Bottolfson, T. 92, R. 52, sec. 17	339	......	2	*a* Many.	
J. B. Daily, in Vermilion	335	300 335	 2	 200	
W. G. Bower, in Vermilion	507	217 507	 3	...... *a* Few.	
T. Jordan, T. 92, R. 52	296	290	2	*a* 9	
Fred M. Smith, T. 92, R. 52, sec. 19	325	......	2	*a* 2	
Noah Wherry, T. 92, R. 52, sec. 33	289	285	2	*a* 40	
Fred Baker, T. 92, R. 52, sec. 34	300	250 300	 3	 50	
L. Larson, T. 92, R. 52, sec. 18	300	140 300	 2	...... *a* 15	
H. Gunderson, T. 92, R. 53, sec. 12	290	......	2	(*a*)	
James Ericson, T. 92, R. 53, sec. 17	320	280 320	 2	...... *a* 25	
J. A. Gunderson, T. 92, R. 53, secs. 11 and 14.	260	230	2	*a* Few.	
C. Hanson, T. 92, R. 53, sec. 6–5	280	230	2	*a* 2½	
A. Hanson, T. 92, R. 53, sec. 14	365	225 365	 2	...... *a* 4	
I. Iverson, T. 92, R. 53, sec. 9	235	225	2	(*a*)	
L. Iverson, T. 92, R. 53, Sec. 15	335	300	2	*a* 16	
O. N. Junker, T. 92, R. 53, sec. 8	305	227 305	 2	 5	Chalk at 130 to 140 feet.
J. Junker, T. 92, R. 53, sec. 6	290	230	2	*a* 10	Chalk at 124 to 140 feet; 35 pounds pressure.
C. Larson, T. 92, R. 53, sec. 14	272	......	2	*a* 4	
L. A. Larson, T. 92, R. 53, sec. 8	205	188	2	*a* 5	
H. Myron, T. 92, R. 53, sec. 15	280	260	1¼	*a* 20	4-gallon flow at 185 feet; 20 pounds pressure.
T. Thompson, T. 92, R. 53, sec. 11	270	200 270	 2	...... *a* 2	
J. Gunderson, T. 91, R. 51, sec. 4	280	270	2	*a* 6	
F. Verzani, T. 91, R. 51, sec. 9	210	190	2	(*a*)	
O. A. Anderson, T. 91, R. 51, sec. 8	275	240	1¼	*a* 20	

[a] Flow decreasing.

All of Clay County appears to be underlain by the water-bearing beds, but, owing to the greatly decreased head of the water, they afford flowing wells only in the lower-lying lands. The limit of the area of flow in the Missouri bottom appears to be in the extreme southwestern corner of the county, and in the valley of the Vermilion River it extends to the northern boundary of the county.

Logs of a number of Clay County wells are reproduced in Pl. XCV.

THE REGION WEST OF THE MISSOURI RIVER.

Very few attempts have been made to obtain artesian waters in the region west of the Missouri River. Two small wells opposite Chamberlain and a well at Fort Randall are the only ones in the vicinity of the river. In the Plains country westward a boring is now in progress on the Rosebud Indian Reservation, at a point 22 miles northeast of Rosebud Agency. In April, 1896, it had gone to a depth of 2,075 feet, but had not reached the Dakota sandstone formation. Calcareous beds were penetrated between 1,500 and 1,650 feet below the surface, which are believed to represent the chalk deposits of the Niobrara formation. It was expected that the underlying Benton shales would be found to have a thickness of about 400 feet, so that the depth to the Dakota sandstone would be about 2,050 feet. The boring is situated on the divide between branches of Oak Creek of White River and the Keya Paha River. It is being sunk by the Indian Bureau of the Interior Department to supply water to the creeks for the watering of stock. It is believed, however, that the boring has but little prospect of obtaining a flow of water, although with the increase of head westward the waters may rise to within a moderate distance of the surface. The region has an elevation of about 2,700 feet above sea level.

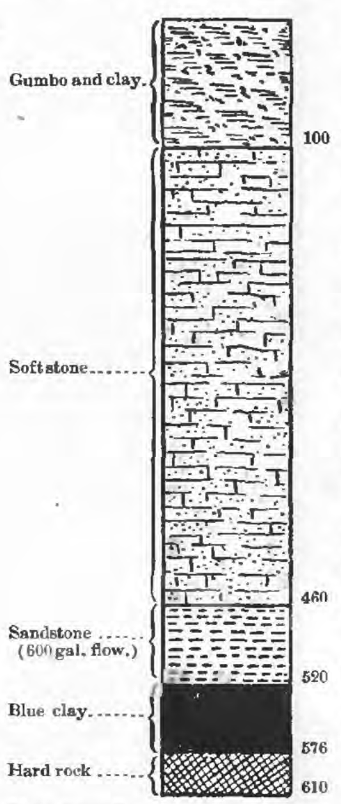
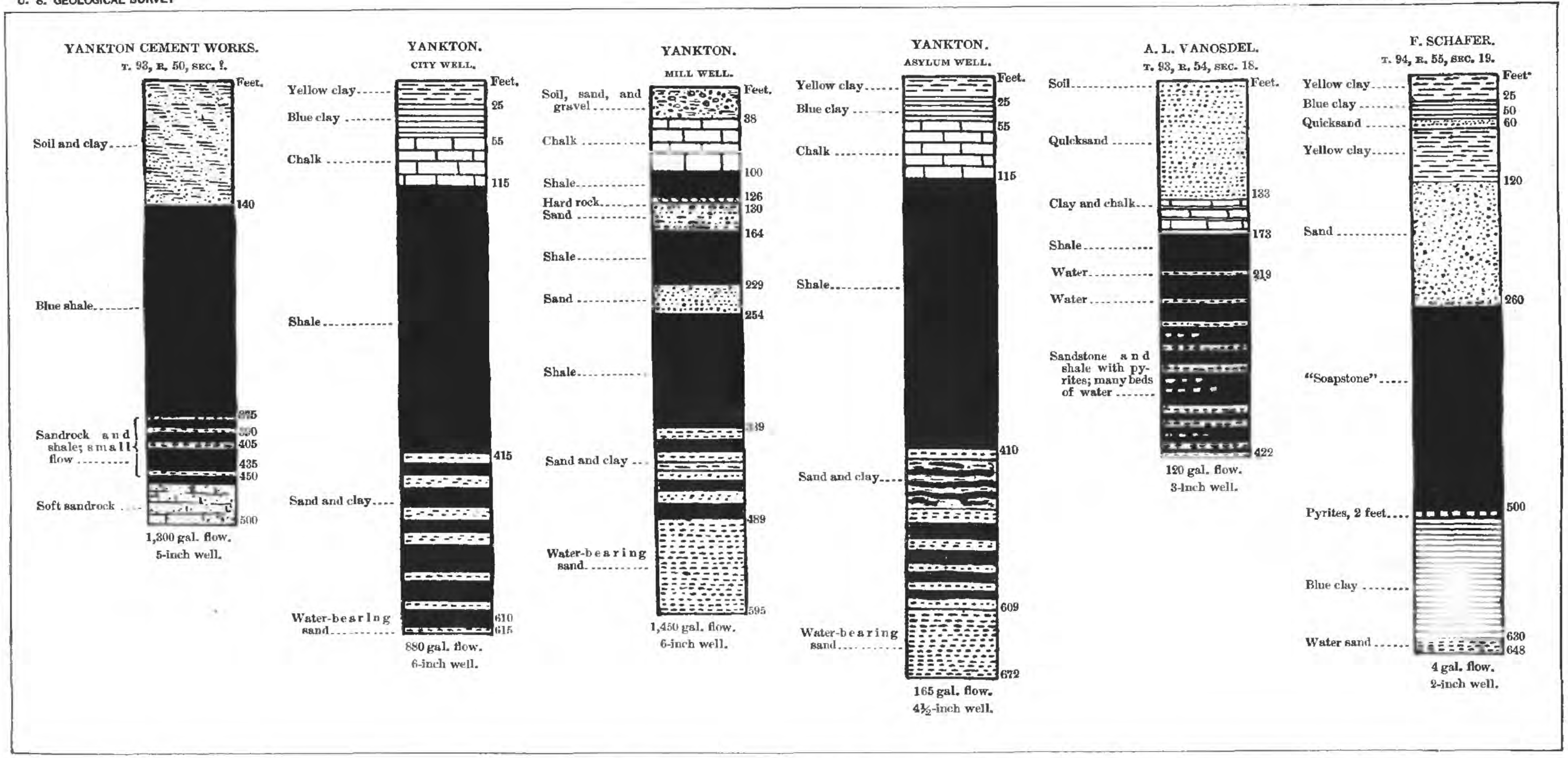


FIG. 58.—Log of well at Fort Randall, Todd County.

The wells opposite Chamberlain yield flows for irrigation. One is on the farm of G. S. Grant, in T. 104, R. 72, sec. 14. It has a depth of 563 feet and a diameter of 2 inches. The first flow was reported at 360 feet, a second flow at 460 feet, and a third at 560 feet. The other well is on the farm of E. A. Barlow, on the bench a mile back from the river, in the southern part of T. 104, R. 71. Its depth is 600 feet and its diameter 2 inches. Its flow is reported to be 2 gallons per minute, and increasing. A flow is reported at 450 feet, which is quite alkaline. Both of these wells draw from a water horizon which was found in the Chamberlain wells at about the same depth, or slightly lower.

The well at Fort Randall, in Todd County, was sunk by the Government for the use of the military reservation. Its depth was 610 feet, its diameter 4 inches, and its original flow 600 gallons per minute.



LOGS OF WELLS IN YANKTON COUNTY, SOUTH DAKOTA.

Owing to corrosion of the pipe, the water has been flowing up the outside of the casing for the past five years and the well is not very useful. The log of the boring, as given by Colonel Nettleton, is represented diagrammatically in fig. 58.

This log is not very definite as to the formations penetrated, but the 60 feet of water-bearing sandstone extending from 460 to 520 feet is no doubt the upper part of the Dakota sandstone.

WELLS IN NORTH DAKOTA.

Outside of the Red River Valley relatively few artesian wells have been sunk in North Dakota. The same water-bearing beds extend under this State which yield such a large supply of water in South Dakota, but wide areas of the country are too elevated for artesian flows. In the Red River Valley there are over 200 wells, and the underground waters are so well located that during this season's field work I did not attempt to study that region. Considerable information regarding the wells has already been published by the United States Geological Survey in a monograph[1] by Mr. Warren Upham, and to this I will refer all who are interested in the Red River region. In the northern extension of the James River Valley a number of successful wells have been sunk to the Dakota sandstone horizon, and there are others at Rutland, Ransom, Tower City, and Devils Lake. To the westward an attempt to obtain artesian flows was made at Bismarck, and another at Mandan, with unsatisfactory results, and in the extreme western part of the State a number of deep borings have been made by the Northern Pacific Railroad Company.

The following is a list of all the wells west of the ninety-eighth meridian for which we have data. The location of many of these wells is shown on the map (Pl. LXIX):

List of deep wells west of longitude 98° W. in North Dakota.

Location, etc.	Depth.	Depth to flows.	Diameter.	Yield per minute.	Pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
Oakes	977	790			
		845			
		870			
		a 937		817	125
Ellendale	1,087	1,042	4⅜–3¾	700	115
Ellendale, W. H. Jones	860	(*b*)			60
Edgeley	1,354	1,300			
		1,350	6	500	60

a Main. *b* Abandoned.

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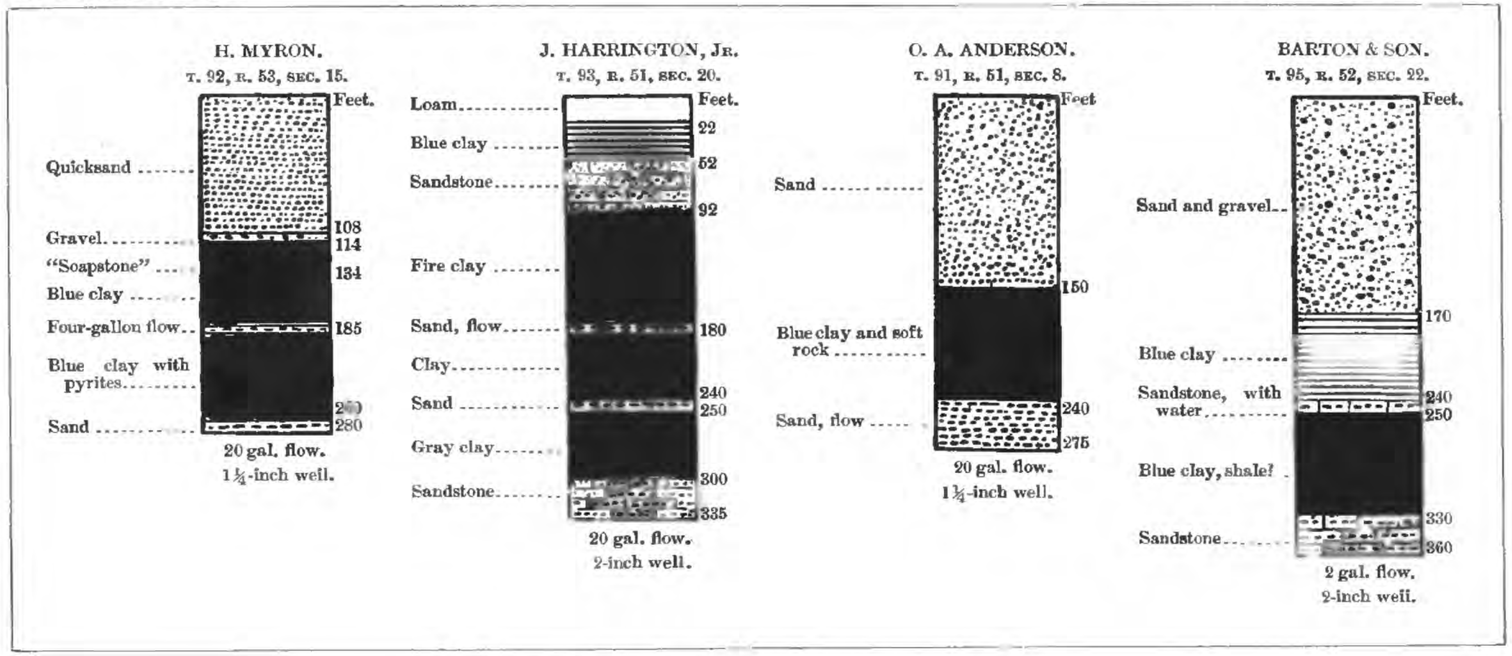
[1] The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, Vol. XXV, Washington, 1895.

List of deep wells west of longitude 98° W. in North Dakota—Continued.

Location, etc.	Depth.	Depth to flows.	Diameter.	Yield per minute.	Pressure per square inch.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	*Pounds.*
Jamestown	1,475	1,385			
		1,458	6¼–3½	460	97
Jamestown Asylum	1,524		8 –3½	4	70
Wimbledon	1,557			200	80
Tower City	716		6 –4½	20–25	53
Devils Lake	1,520		8 –3	82	20
Mandan	2,000	357	10 –4	3	(?)
Bismarck	1,315		8 –4½	(a)	
Dickinson	1,325			(a)	
Medora	941		4	33	15
Sims	1,311			(a)	

[a] No flow.

These wells quite definitely indicate many of the conditions under which artesian waters occur in a portion of North Dakota. The wells in the James River Valley obtain large flows from the Dakota sandstone horizon, but owing to the descent of this formation to the northward the waters lie deeper in the region north of Oakes than in South Dakota. Thus at Jamestown they are over 1,400 feet below the surface, although toward Devils Lake they rise again slightly. The relations of the water-bearing beds to the James River Valley as far north as Jamestown are shown in section 1 of Pl. LXXI. The nature of the materials penetrated by the borings, as reported by Colonel Nettleton, is indicated in Pl. XCVI. The pressures in wells of the James River Valley in North Dakota are not quite so great as in those farther south, but the elevation above sea to which the waters will rise remains relatively constant, as shown in Pl. LXX. This head, expressed in altitudes above sea level, varies from 1,727 feet at Ellendale to 1,614 feet at Jamestown, which is insufficient to bring the water to the surface of the high coteau lying west of the valley. The steep eastern face of this coteau passes near Lorraine, Merricourt, and Windsor station, and, as shown on Pls. LXIX and LXX, its high slopes delimit the areas in which artesian flows may be obtained between the James River Valley and the Missouri River. To the eastward of James River the country is low and rolling, and gradually sinks into the low plains of the Red River Valley. All of this region appears to be within reach of flows, excepting possibly the summits of a few higher areas of very small extent. The water-bearing beds rise rapidly to the eastward and come near the surface in the Red River Valley. Their waters appear to pass into the gravels and sands at the base of the heavy overlying drift mantle, but are kept from flowing freely out on the



LOGS OF WELLS IN CLAY COUNTY, SOUTH DAKOTA.

surface by the widely extended sheets of drift clays. The general structure is shown in fig. 59.

Many artesian and other wells are sunk to the waters in the Red River Valley, and in the aggregate a large supply is obtained. No doubt some of the waters in this valley have a local source under the drift, but it is thought that much of the supply and nearly all of the pressure are derived from the edge of the Dakota sandstone. This formation has been recognized in some of the deeper wells, notably at Castleton, which lies well within the area underlain by the Dakota sandstone. The descent of the water-bearing bed from Castleton to Jamestown appears to be at a relatively uniform rate, as indicated by the wells at Staples and Tower City. The principal features are shown in fig. 59.

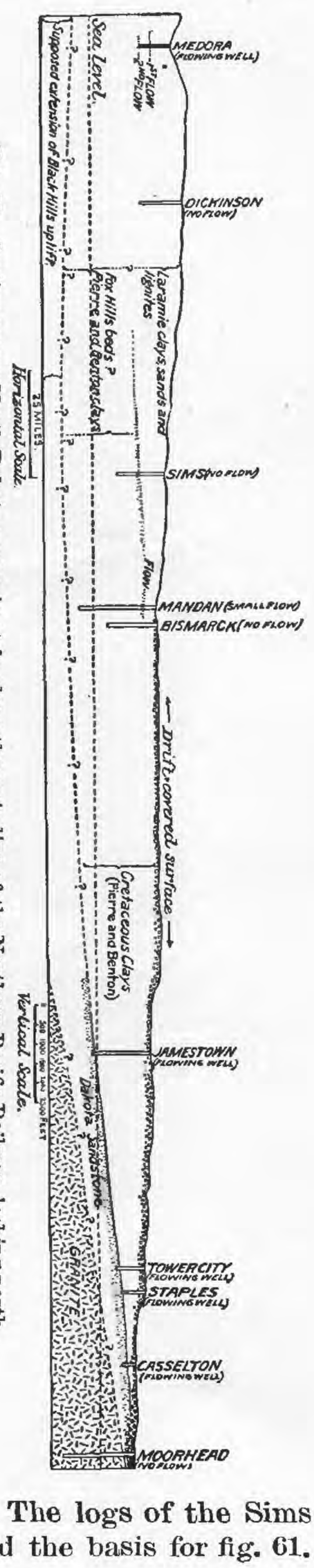


Fig. 59.—Section across North Dakota approximately along the main line of the Northern Pacific Railway, looking north.

This section also sets forth all available information which we have regarding the general structural relations in the western portion of the State. Unfortunately, the 2,000-foot boring at Mandan was apparently not quite deep enough to reach the Dakota sandstone, so that the rate of descent of this formation west from Jamestown can be shown only approximately. It may be greater than I have suggested in this section, but probably not very much so. There is a fair degree of probability that there is a northward prolongation of the Black Hills uplift in the western portion of the State, which has at least some effect in North Dakota, as suggested in this section. The Medora, Dickinson, and Sims wells throw some light on the conditions in the higher formations in the western part of the State. The two flows in the Medora well are from sandstones in the Laramie formation; the borings at Dickinson and Sims are as yet unsuccessful. According to Mr. Barrett, the first flow at Medora rises 45 feet above the surface, and the second flow to over 100 feet. The water is soft, somewhat sulphurous, and is in good supply. Diagrams of the logs of the Medora and Dickinson wells were kindly supplied by Mr. McHenry, of the Northern Pacific Railroad Company, and they are reproduced in fig. 60. The logs of the Sims well, as given from memory by the driller, afford the basis for fig. 61.

The logs show remarkable similarity when the distance separating the wells is considered, and this has in a measure justified the connection of many of the coal and other beds. The Dickinson well, however, has found no water to a depth of 1,325 feet. In the Sims boring no

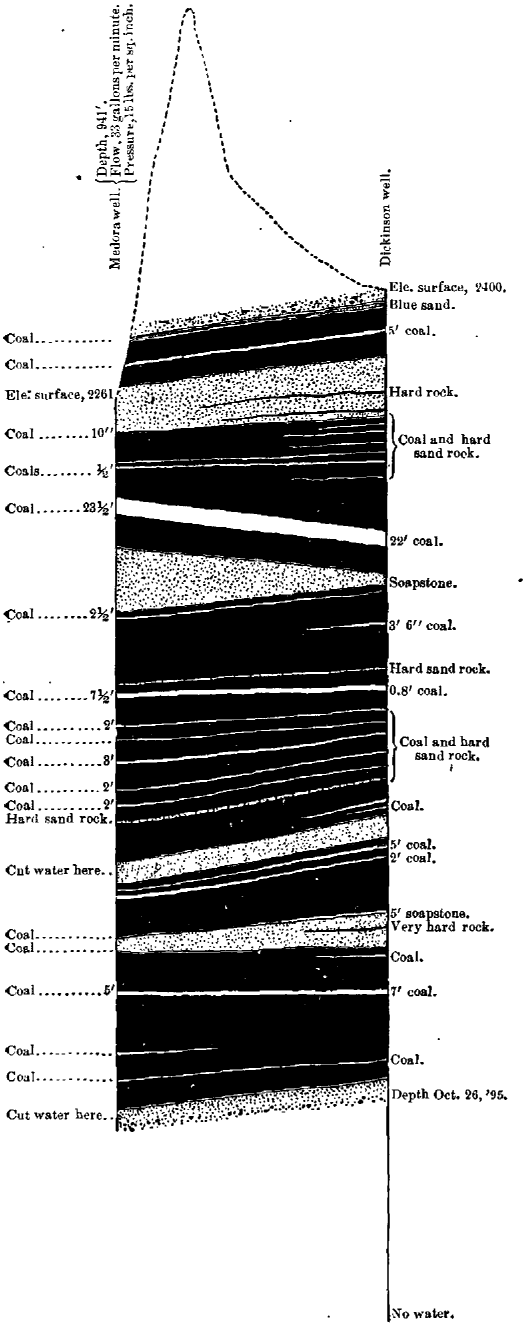


FIG. 60.—Logs of wells at Medora and Dickinson, N. Dak. These wells are 39 miles apart.

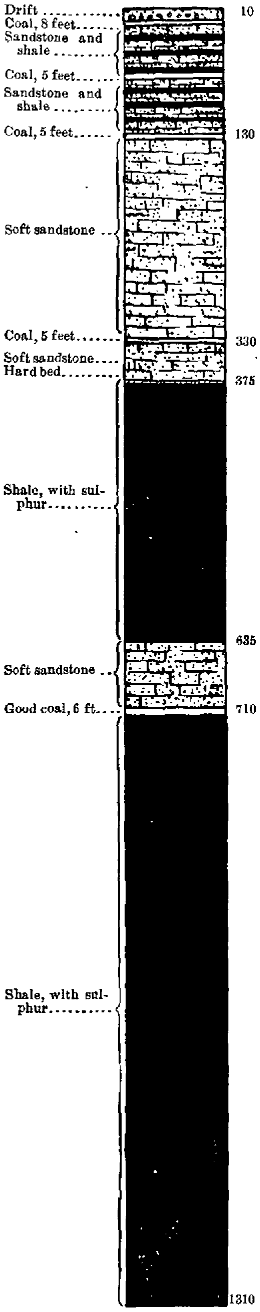
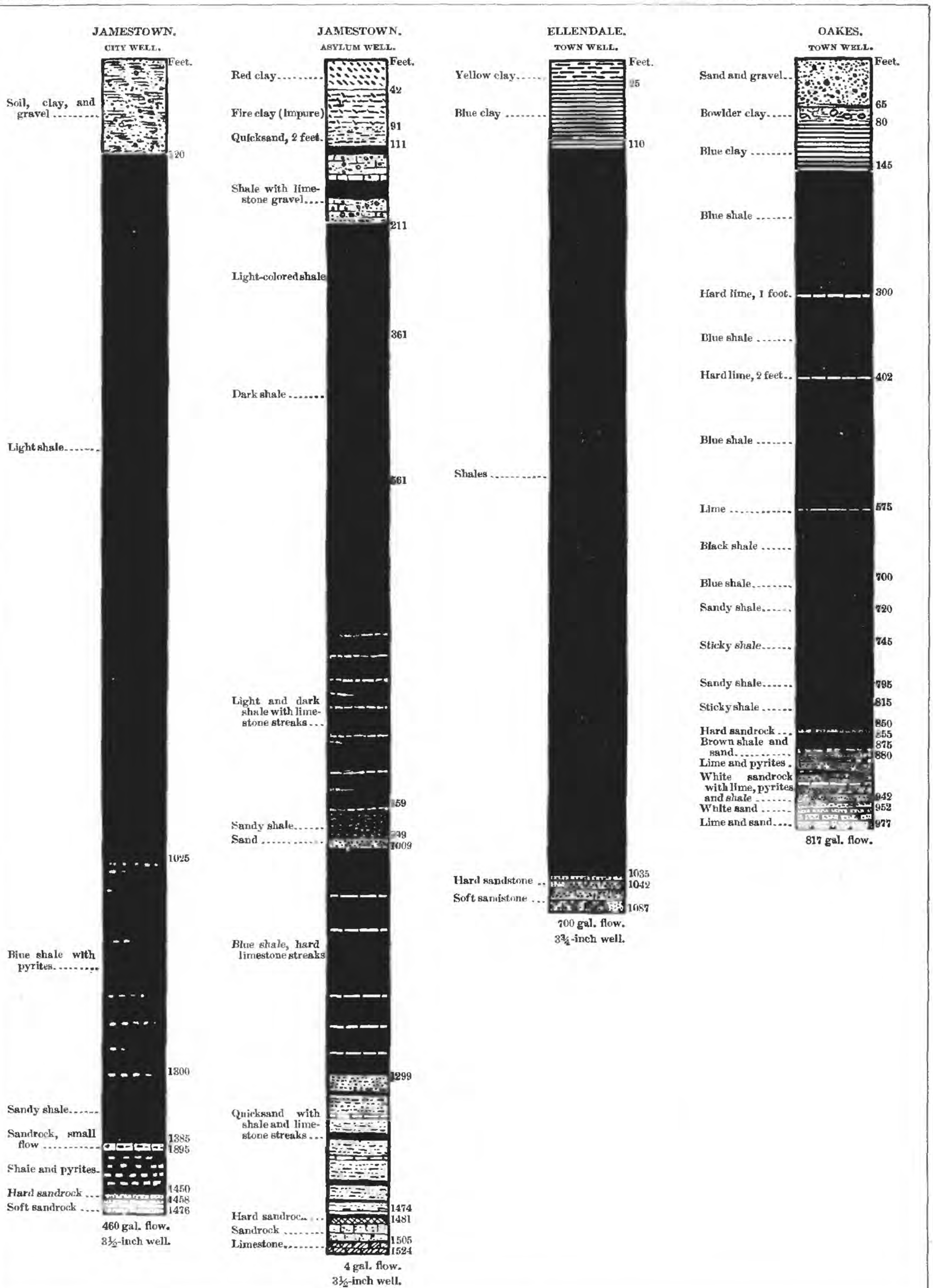


FIG. 61.—Log of boring at Sims Station, N. Dak.



LOGS OF WELLS IN JAMES RIVER VALLEY, NORTH DAKOTA.

water has been found to a depth of 1,311 feet. In this boring the last coal and sandstone, at a depth of 711 feet, appear to indicate the position of the base of the Laramie formation, for the underlying material is a very uniform mass of pyritiferous clay extending 600 feet to the bottom and apparently representing the Pierre formation. The presence of the Fox Hills beds, if they are here included, is not recognized.

The Mandan well was a great disappointment to its projectors, for when the contract was made it was thought that the water-bearing bed would surely be reached within 2,000 feet of the surface. The boring cost $10,000. The only water obtained is a small flow from a depth of 357 feet, which is estimated at 3 gallons per minute, but it is soft and clear. It flows into a cattle trough and is hauled away in barrels, largely for use in washing clothes. Below the thin bed of loose sand rock which affords the present flow, another sand rock with a small flow was reported to extend from 410 to 470 feet. From 470 to 1,500 feet the material was shale of various gray and blue colors; from 1,500 to 2,000 feet the materials were mainly shale, so far as I could learn, but no reliable information could be furnished. The Bismarck boring found no flows at all. It is reported to have been in shale with occasional thin limestone beds to a depth 1,315 feet. It fell very far short of reaching the Dakota sandstone water-bearing beds.

THE PRESSURE AND HEAD OF THE ARTESIAN WATERS.

One of the most characteristic features of the waters of the Dakota sandstone is their high pressure at many of the wells. This pressure averages 125 pounds to the square inch over a wide area in the James and Missouri valleys, and in about a dozen wells it is over 150 pounds. At Bonilla the pressure is reported to be 175 pounds and at Redfield 177 pounds. In Pl. XCVIII I have brought together all the information available as to closed surface pressures in wells supposed to have reached the Dakota sandstone waters. The colors indicate the areal distribution of pressures for each 50 pounds interval. The greater number of these pressures were obtained from the report of Colonel Nettleton, but several were derived from other sources. In nearly all cases they appear to be satisfactorily accordant, although in some instances the pressures at the wells at present are less than those determined some years ago.

Probably a knowledge of the pressures of other wells would lead to some slight modification of the areas as now colored on the plate, but the general outlines are quite definitely determined. The areas of greatest pressure are in the lowlands of the central portion of the James River Valley and along the Missouri bottom in the vicinity of Pierre. The pressures decrease rapidly up the slopes on either side of the James and Missouri valleys, as indicated, notably at Highmore, and more gradually to the northward up the James River Valley.

South of the latitude of Huron there is a gradual decrease of pressure, which is of course most rapid in the higher lands, as at Tripp, Scotland, and Layson, and some scattered elevated areas of doubtful flow. A short distance below Vermilion the pressure dies out entirely in the Missouri bottom.

There is every reason for believing that these pressures are purely hydrostatic or due to the disposition of water "to find its own level." The waters passing into the Dakota sandstone in the high regions adjoining the Black Hills and the Rocky Mountain ranges should be expected to have much greater pressure than they have in the relatively low lands of the eastern Dakota region. When the highest pressures in the James River Valley are calculated into head, or the height to which the pressure would lift the water in an open tube, it is found that the amount is only a trifle over 1,700 feet above sea level, or 1,500 feet less than the altitude at which the water appears to pass underground around the Black Hills. This head is calculated by multiplying the pounds pressure per square inch by 2.3 feet,[1] the number of feet to which 1 pound pressure will lift a column of water 1 inch square. By adding the altitude above sea level of the mouth of the well a convenient general plane for comparison is introduced. For instance, the water of a well having a pressure of 150 pounds would rise in an open tube to a height of 345 feet (150 by 2.3) above the mouth of the well, and if this were 1,000 feet above sea level the total altitude to which the water would rise is 1,345 feet. Of course this is not influenced by the relative sizes of outlets or volume of water, nor by time, after hydrostatic balance is once established.

I have given the calculated heads above sea level in Pl. LXX for all the wells to Dakota sandstone waters of which the pressures have been recorded. They are placed on this plate in order to indicate their bearing on areal distribution of land in which flowing wells should be expected. They are in greater part also shown graphically in Pl. LXXI. It will be noticed that the greatest head above sea level is indicated by the well at Highmore, on land so elevated that the actual surface pressure is very low. There is in general an increase in altitude of head to the northwest and a decrease to the east and south, in part as in the case with the actual well pressures, but not solely influenced by the altitude of the land, which is an important factor in the surface pressures at the wells. Some features of the decrease of head along a portion of the James River Valley and thence down the Missouri River are shown in section 1, Pl. LXXI, and again in somewhat larger vertical scale in the profile fig. 62.

It has been suggested that the decrease of pressure and head to the southeastward, particularly the head above sea level, is due to surface leakage of the waters from the Dakota sandstone in the outcrop of

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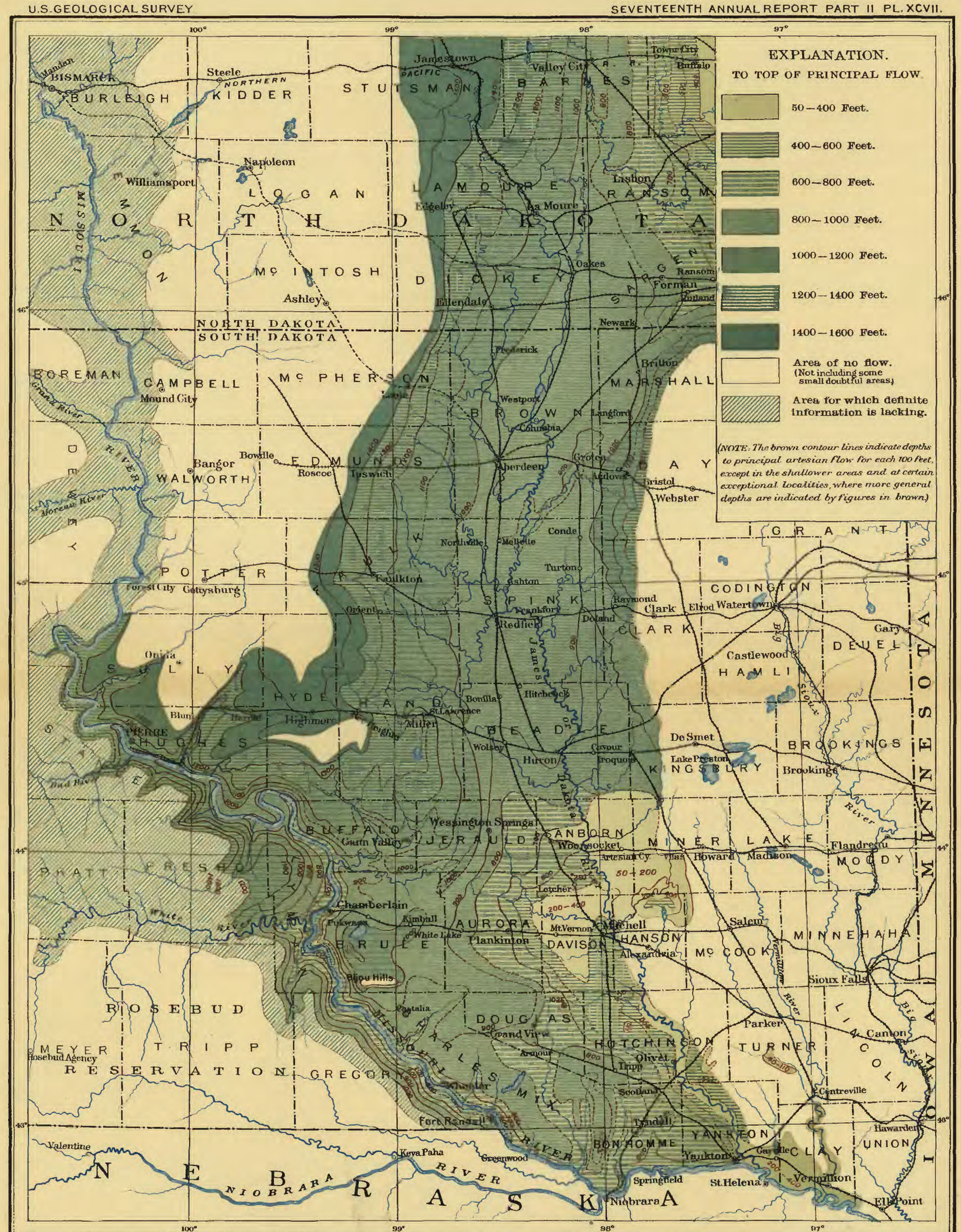
[1] This is a closely approximate figure, for the amount varies slightly with temperature, barometer, salinity, etc.; 2.3104 is often taken as the multiplier, but the round number answers our present purpose.



MAP INDICATING DEPTHS TO TOP OF PRINCIPAL ARTESIAN FLOWS IN A PORTION OF THE DAKOTA BASIN

BY N. H. DARTON

Scale 0 5 10 15 20 25 50 Miles

this formation in the southeastern corner of the State and southward. I believe this suggestion fully accounts for the phenomena, which, so far as I can now see, are all accordant. It may be noticed in fig. 62 that the line of head above sea level passes beneath the Missouri River between Vermilion and Elk Point, in the vicinity of the outcrops of the top of the Dakota sandstone formation as it first rises to the surface. The declivity from Huron and Woonsocket toward Mitchell is also explained by the supposed approach of the Dakota sandstone near to the surface in the Mitchell region, where, no doubt, considerable leakage occurs. A depression of the line is also indicated by the Day well near Mellette, but this indication is probably due either to erroneous data, such as a leak in the well, or to some other defect which would record too low a pressure. The narrow area of low pressure north of Hitchcock is apparently directly related to a local cause—a ridge of granite, which will be considered later in this chapter. From Aberdeen to Jamestown the head above sea level, as shown in Pls. LXX and LXXI, drops to 1,544 feet at Frederick, rises to 1,727 feet at Ellendale, is 1,631 feet at the asylum near Jamestown, and 1,614 feet in Jamestown. As these calculations all include the variations of head due to the rise and fall of the water-bearing stratum, Pl. XCIX has been prepared to show the variations of pressure calculated at a plane of uniform altitude, so as to exclude the factor of the position of the water-bearing stratum. A plane 1,000 feet above sea level has been the one selected, and to the surface pressures have been added the calculated pressures from the surface to this plane. Of course only those wells have been indicated which are known or supposed to draw from Dakota sandstone horizons.

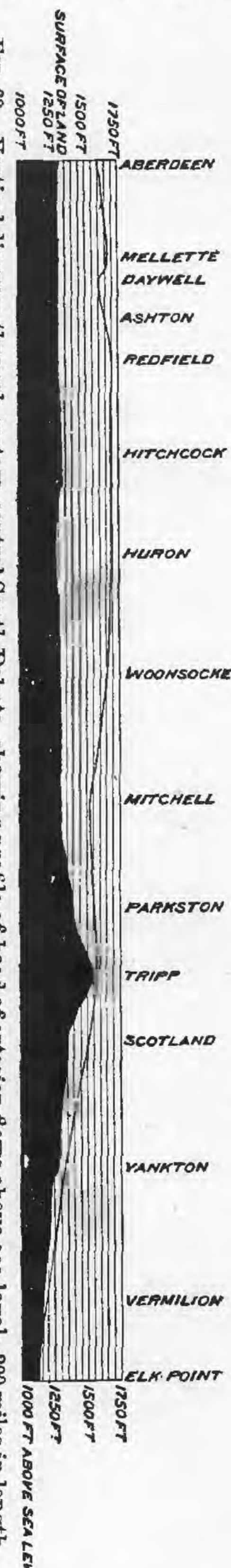


Fig. 62.—Vertical diagram through eastern-central South Dakota, showing profile of head of artesian flows above sea level; 200 miles in length.

In descending a well the pressure increases directly in proportion to the weight of a corresponding column of water, or 1 pound, approximately, for each 2.3 feet; so that, for instance, in a well 1,203 feet above sea level, with a surface pressure of 100 pounds per square inch, the total pressure at 1,000 feet above sea level is 200 pounds per square inch. This is of course independent of the position of the water-bearing bed, and gives the direct means of comparing the true rate of diminution of pressure due to leakage. Pl. XCIX shows the result of such calculation for all the wells of which we have suitable data, with the areal relations brought out by tints. The most prominent feature in this illustration is the regular decrease of pressure to the eastward. This is probably equally regular in all the region lying between the James River Valley and the eastern border of both South Dakota and North Dakota north of latitude 42° north, but data are lacking for this belt, except in the vicinity of the Northern Pacific Railroad. The amount indicated at Highmore may reasonably be expected to increase to the northwestward, but we shall have to await further developments of wells in that direction before this can be determined. No doubt the well now in progress on the Rosebud Reservation will throw light on the rate of increase to the southwestward, but unless this rate increases in rapid ratio west of the Missouri River the Rosebud boring will be found to be on land too elevated for a surface flow. Assuming that the elevation at this well is 2,700 feet, which is the best estimate now available, there will have to be a pressure of 740 pounds to the square inch at 1,000 feet above sea level in order to give a surface flow.

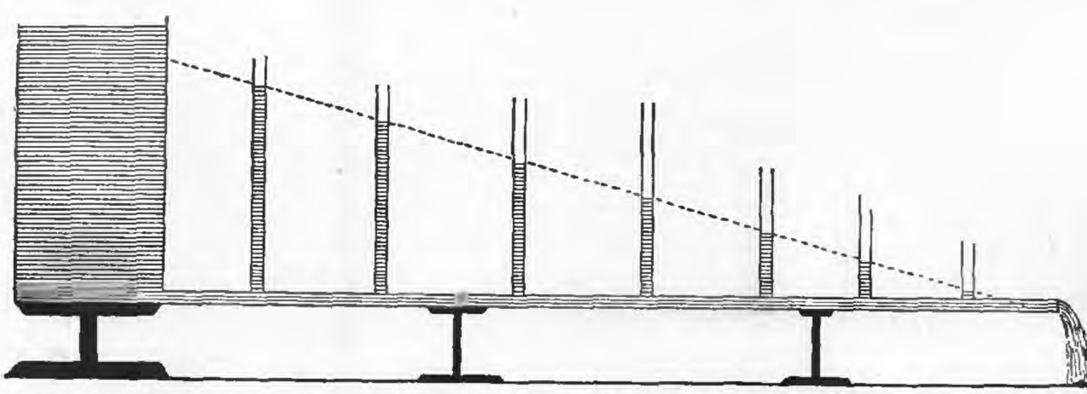
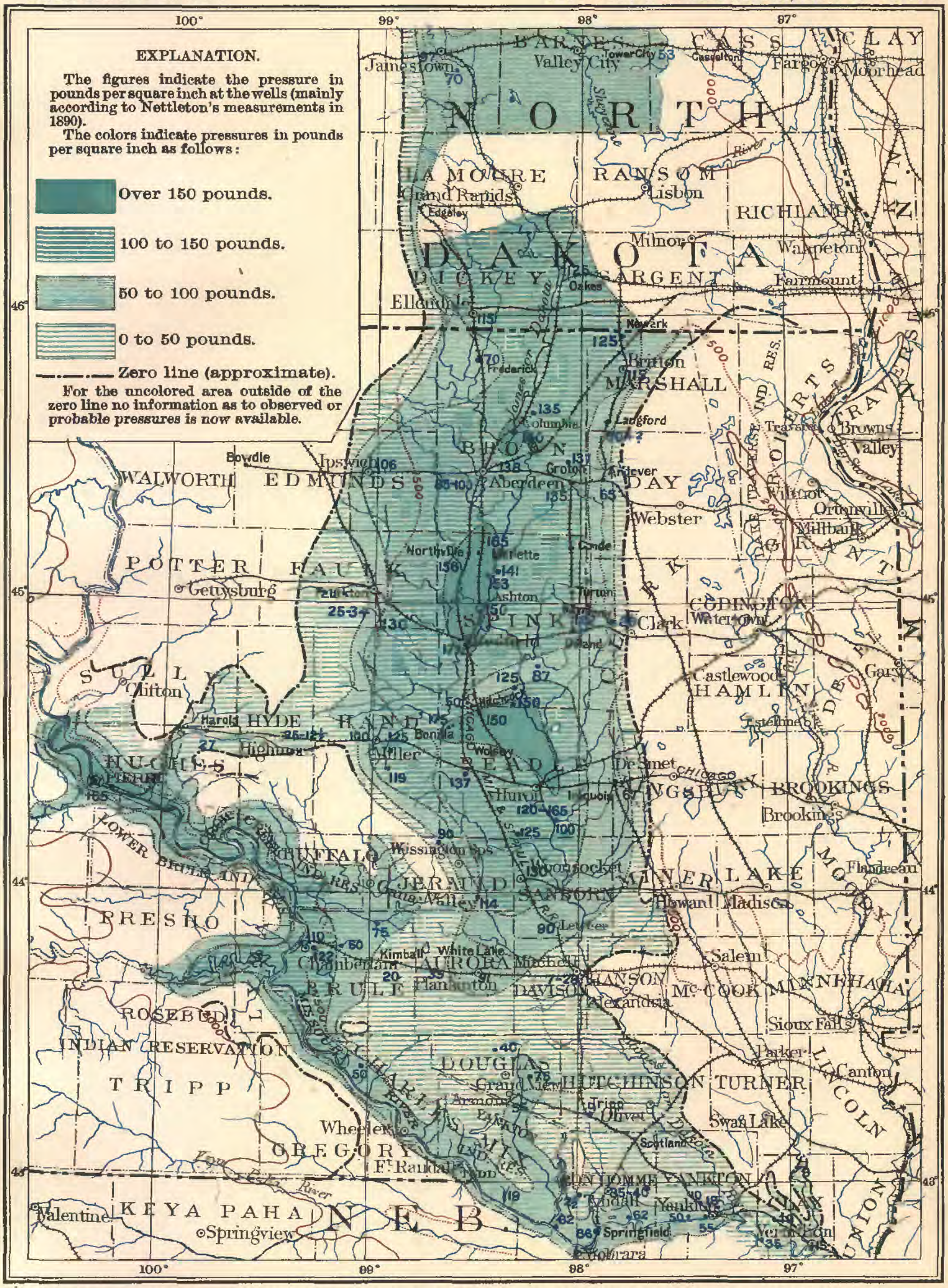


FIG. 63.—Diagram of apparatus for illustrating the declivity of head of liquids flowing from a reservoir.

As illustrating some known conditions under which pressures gradually diminish toward a leak, I have introduced in fig. 63 a diagram from Daniell's Text-book of the Principles of Physics, page 286.

This illustration appears to be closely parallel in its conditions to those which we find in the Dakota artesian basin, although, of course, the same regularity could not be expected under the more variable conditions that occur in nature as is found in a carefully constructed physical apparatus.

Returning to Pl. XCIX, it will be seen that there are a number of exceptional features for which no explanations are evident, but they have no important bearing on the general relation. The local decreases of altitude of head at Frederick, Aberdeen, and in the new power well at Chamberlain are the most anomalous of these, and they can not at present be explained. We should have expected a much higher actual pressure than 110 pounds (104 pounds at last reports) in this power well, for it is on land far lower than the Chamberlain city well, which was reported to have a considerably higher actual pressure.

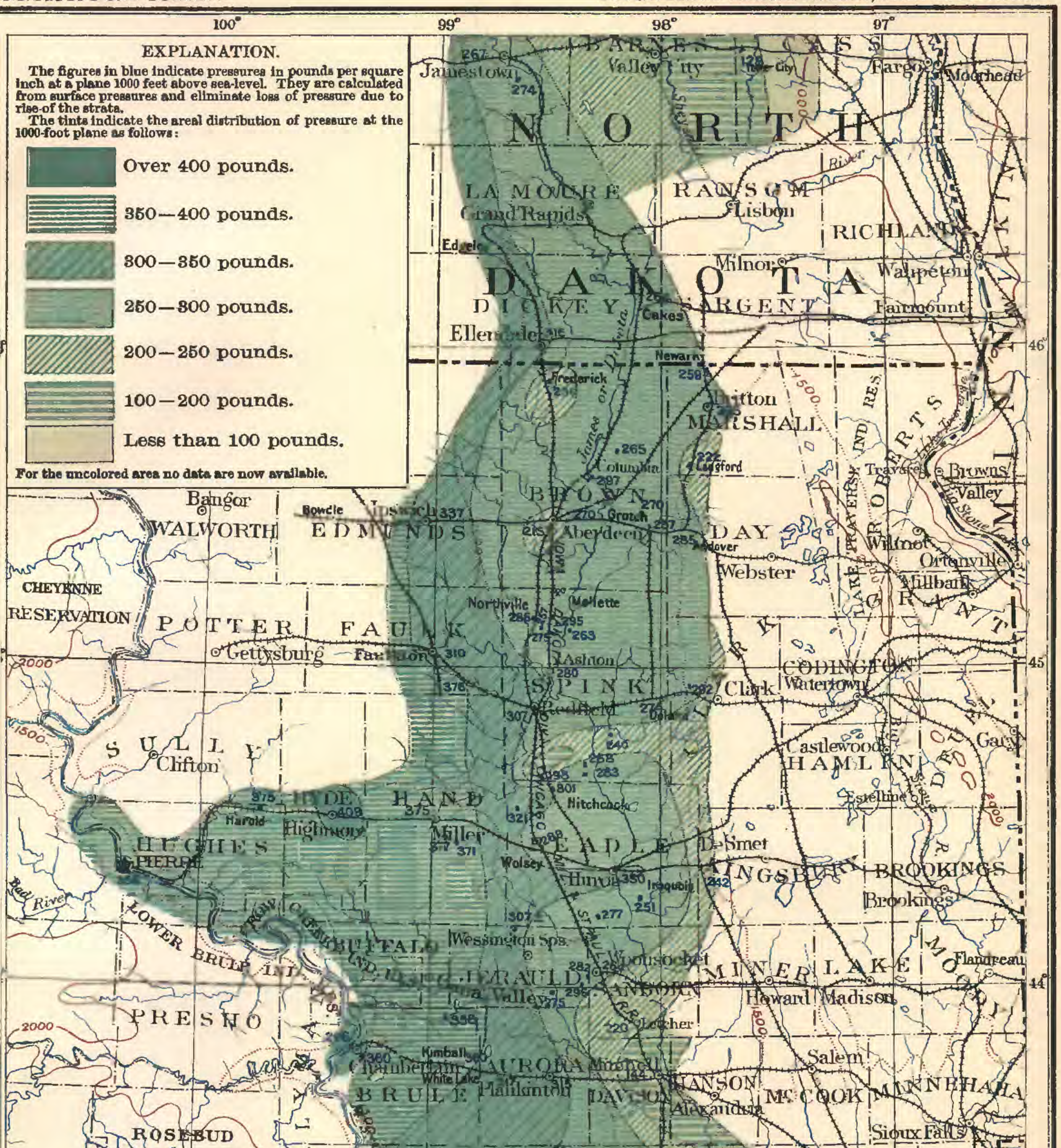


MAP SHOWING DISTRIBUTION OF PRESSURE IN WELLS IN DAKOTA ARTESIAN BASIN

BY N. H. DARTON

SCALE: 0 5 10 20 40 80 MILES

JULIUS BIEN & CO. N.Y.



MAP SHOWING THE INFLUENCE OF LEAKAGE (AND OBSTRUCTIONS) ON THE PRESSURE OF THE ARTESIAN WATERS IN A PORTION OF THE DAKOTA BASIN

BY N. H. DARTON

SCALE: 0 5 10 20 40 80 MILES

JULIUS BIEN & CO. N.Y.

The diminution of actual pressure, head, and pressure at the 1,000-foot plane, as shown in Pls. XCVIII and XCIX, at the wells north of Hitchcock, notably the Glidden well, is apparently due either to the cutting off of the lower waters by the buried granite ridge shown in Pl. C, or by loss of pressure by leakage into higher beds, due to increased coarseness of material adjacent to the granite ridge. The Glidden well, according to Mr. P. J. Stacey, has a closed pressure of only 50 pounds, although its flow is fairly large. The Motley well is reported by its owner to have a pressure of only 87 pounds. Both of these wells are on relatively low ground.

In the Mitchell region the decrease of pressure is due either to local leakage, as before suggested, or possibly to the fact that the water is from a horizon above the one which gives the higher pressure in wells to the north, west, and south. Just east of Mitchell, outside of the area of flowing wells, we are not sufficiently certain of the horizon of waters in pump wells to consider their pressures at the 1,000-foot plane or to introduce them as evidence in this connection. It is possible that the local decrease of pressure in the Missouri Valley at Chamberlain, and for a distance southward, may be due to leakage of water in the deeper portions of the valley, where the covering of shales over the Dakota sandstone has been deeply excavated. This idea appears to be borne out by the occurrence of several springs of tepid water with the same temperature as that of the waters from the deep wells. Before accepting this suggestion, however, we should bear in mind the possibility that these warm springs may result from the decomposition of pyrites, which is so general in the shales all along this portion of the valley, and is probably quite adequate to account for tepidity of superficial waters.

There is a condition which it appears to me may probably account for some variations in pressures in different wells in the same vicinity when these wells draw from different sand beds in the Dakota formation. The Dakota sandstone formation is exceedingly variable in the relations of its component beds, particularly in the disposition of beds of clay among the sandstones. It is probable that some of the sand beds are sealed to the eastward, either by clay beds inclosing them or by an increase of fineness of materials and intermixture with clay. Of course the waters in those beds of sand which extend continuously from the source of the waters to the outcrop of the formation at low levels in the Missouri Valley below Vermilion would lose pressure more rapidly than those sealed to the southeastward by clays or imperviousness, so that their waters would not be so free to flow out in the surface outcrops.

The head and pressures of waters in horizons higher than the Dakota sandstone formation have not been especially studied. Only four such pressures have been reported, as follows:

Locality, etc.	Pressure.
	Pounds.
Arland well, T. 103, R. 62, sec. 15	45
Schlund well, T. 104, R. 62, sec. 26	26
Frazier well, T. 104, R. 61, sec. 27	95
Dougan well, T. 104, R. 63, sec. 21	45

These wells all appear to draw from sand beds above the Dakota horizon, and, excepting possibly the Frazier well, they exhibit lower pressures than those of wells to the Dakota waters in the same vicinity.

The pressures of waters in the basal beds in the drift formation, both in the Red River region and in the Sanborn-Miner-Hanson County area, appear to be derived from the underlying formations, probably the Dakota sandstones to the northward and the chalk or local sand-bed horizons to the southward. It is found that these areas of artesian waters in the drift exist where the edges of the older water-bearing formation lie near to the surface and the overlying drift contains gravels and sands below and a protecting cap of clay above, and the altitudes are sufficiently low for the head of the water to carry it to the surface. Where the clay does not exist in the drift, which is rare, the water is free to flow out onto the surface, and of course no pressure will be found. When the altitude is too high, as it is in most areas along the eastern coteau, the head is not sufficient to afford a surface flow of water when the drift is penetrated.

FLOOR OF THE ARTESIAN BASIN.

The rocks which underlie the water-bearing formations of the artesian basin pass beneath the surface in western Minnesota, western Iowa, and a portion of western South Dakota. The underground surface of these rocks slopes more or less steeply to the westward, and it is finally carried to a considerable depth in the region between the James River Valley and the Black Hills. It is reported that in a number of wells east of longitude 99° this floor of underlying rocks has been found, and in some instances penetrated to a considerable depth. In the surface outcrops the "bed rock," as it is popularly termed, is found to be granite in the vicinity of Big Stone Lake along the Minnesota Valley, the red quartzite of Sioux Falls in the southwestern corner of Minnesota and in a narrow belt extending westward nearly to Mitchell, and limestone in the Missouri River depression below Sioux City. In the records of borings which are claimed to have reached bed rock, the nature of the rocks has been more or less definitely recognized, but in some cases the drillers have simply reported "hard rock" or "very hard rock," giving no clue to its character. In a few instances samples have been obtained and submitted to persons qualified to determine their petrographic nature, but more often we have only the judgment of the well drillers. Ordinarily, these persons have been able to recognize the red quartzite of Sioux Falls without much doubt, but with other rocks their judgment is open to considerable question. It is claimed also that in several instances rocks collected on the prairie have been placed in the wells and afterwards churned up by the boring machine, either for mischief on the part of some foolish person or by the driller for the purpose of giving the impression that he had reached bed rock and could abandon further boring.

In the following list I have given all the data that I have been able to secure regarding the occurrence of bed rock in borings in the eastern portion of the Dakotas and in the immediately adjoining portions of adjacent States:

List of wells to or into bed rock, mainly in South Dakota.

Location, etc.	Rock.	Depths.
		Feet.
Jamestown Asylum	Hard limestone	1,505–1,524
Aberdeen	Quartzite	1,221–1,267
	Granite	1,267–1,300
Budlong well, T. 114, R. 62, sec. 18	Quartzite	922– 995
	Granite	995– 998½
Glidden well, three-fourths of a mile west-northwest of Hitchcock.	Quartzite	1,083–1,142
	Granite	1,142–1,150
Motley well, T. 115, R. 61, sec. 7	"Very hard rock" at	1,050
Wolsey	"Very hard rock"	928– 930
Bohri well, near Raymond	do	1,198–1,200
De Smet	"Rock"	1,200–1,610
Brookings	Quartzite at	556?
White Lake [a]	Sioux Falls quartzite	850– 863
Henneaus's well, T. 103, R. 66, sec. 34	Sioux Falls quartzite at	842
Plankinton [a]	Sioux Falls quartzite	745– 830
T. 104, R. 58, sec. 24	Granite	512– 518
T. 104, R. 58, sec. 36	Quartzite at	480
T. 104, R. 57, sec. 13	"Hard rock" at	204
Fulton	Quartzite at	30
T. 104, R. 60, sec. 25	"Hard rock" at	115
Doxheimer well, T. 103, R. 57, sec. 11	"Jasper" at	153
Alexandria	Quartzite at	40
	With sandstone and water below, and in one well hard rock	490– 496

[a] From Nettleton's report, loc. cit.

List of wells to or into bed rock, mainly in South Dakota—Continued.

Location, etc.	Rock.	Depths.
		Feet.
T. 104, R. 59, sec. 29 ?	Quartzite at	100
Spencer	Jasper at	100
10 miles southeast of Salem	Quartzite at	170
Salem	Sioux quartzite	220- 247
West Point region	Quartzite at	300
Humboldt region	do	140- 153
Sioux Falls	do	0- 575
County well, T. 100, R. 62, sec. 18	Granite at	1,025
County well, T. 100, R. 64, sec. 26	Hard rock, "granite"	937
7 miles north of Parker	Quartzite at	140
Parkston	Sioux Falls quartzite	510- 522
Do	Sioux Falls quartzite at	542
Menno	Sioux Falls quartzite	410- 417
Well in center of Turner County	"Very hard rock"	510- 513 or 556- 559?
Well 7 miles southeast of Canastota	Quartzite at	140
Fort Randall *a*	"Hard rock"	576- 610
Scotland *a*	Quartzite at	535- 587
Tyndall *a*	do	735
5 miles north of Alcester	"Hard rock" at	480
Layson well, T. 94, R. 61, sec. 22 *a*	"Very hard rock"	1,074-1,075½
Elk Point	"Hard rock" at	303
Do	do	367
Millbank *b*	Granite	280- 303
Brown Valley, Minn. *b*	Granite?	425- 465
Moorhead, Minn. *c*	Granite	360-1,750
Ponca, Nebr. *a*	Sandy shale and green clay.	420- 455
	Limestone	455- 498
Sioux City, Iowa *d*	Limestone, chalky at top.	335-1,255
	Sand, marl, etc	1,255-1,320
	Limestone and sandstone.	1,320-1,510
	Quartzite?	1,510-1,525
	Granite or gneiss	1,525-2,071

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a From Nettleton's report, loc. cit.

b N. H. Winchell, Notes on some deep wells in Minnesota: Geol. and Nat. Hist. Survey of Minn., 14th Report, p. 14, St. Paul, 1888.

c N. H. Winchell, Natural gas in Minnesota: Geol. and Nat. Hist. Survey of Minn., Bull. No. 5, pp. 27-31, and later information as to total depth.

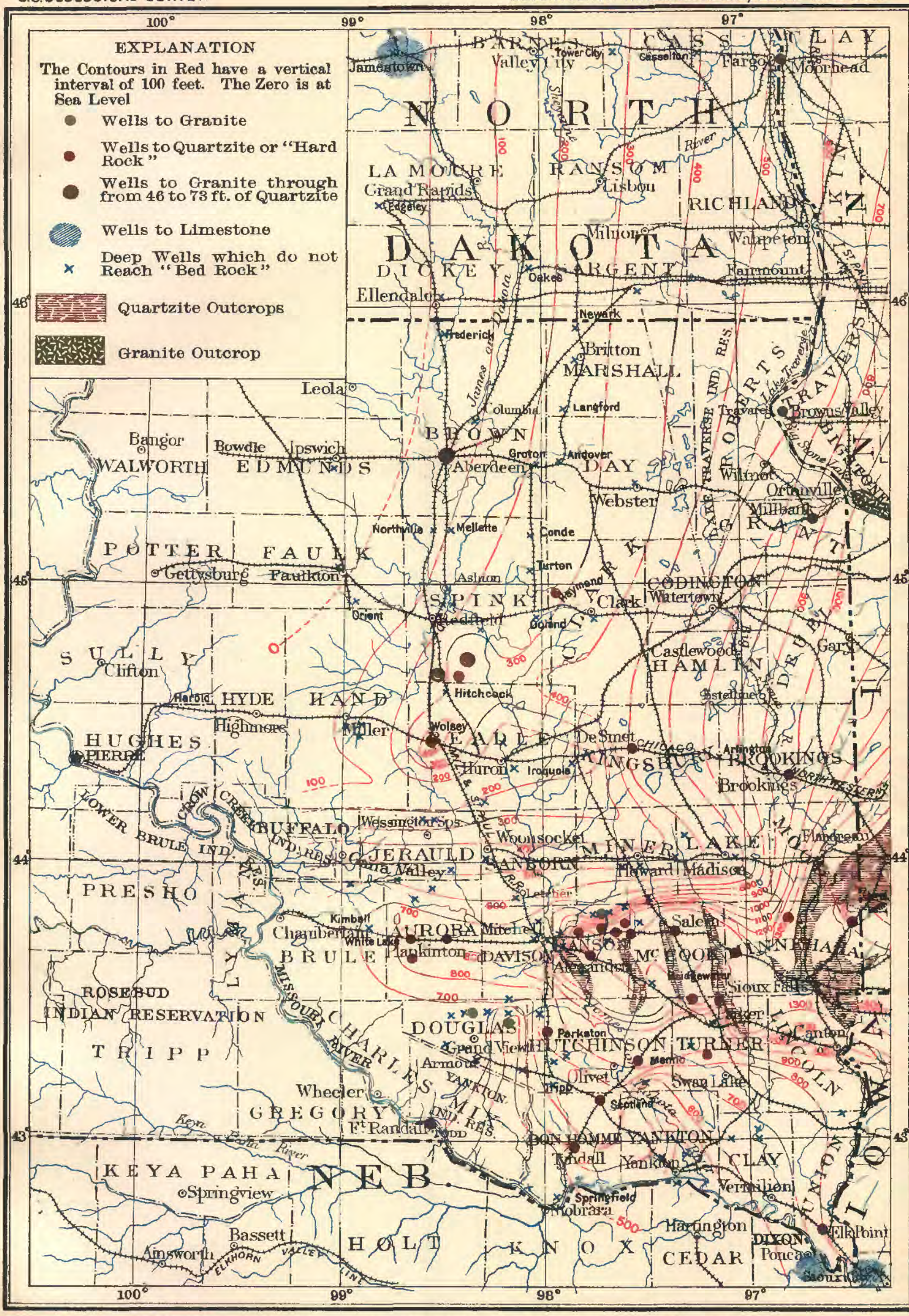
d J. E. Todd, Notes on geology of northwestern Iowa: Iowa Acad. Sci., Proc., 1891.

These data are in the main quite satisfactorily accordant both with themselves and with the general structure as shown in the sections in Pl. LXXI. A few of them suggest rather surprising conditions, but on the whole the evidence as to the distribution of the various rocks and the underground contour of the surface on which the water-bearing beds of the Dakota sandstone lie imposes no great tax on our credulity. This underground contour is represented in Pl. C with as much detail as the data would permit. The general form of all the principal features is indicated, at least approximately, by the experience of more than any one well. It is undoubtedly the case that more complete data, or different interpretation of certain well records, might suggest modification of the contours shown, but it is thought that it would be only in respect to minor details. The high quartzite ridge extending underground nearly due east and west through Minnehaha, McCook, and Hanson counties, and prolonged with diminished height to White Lake and beyond, is perhaps the most noteworthy feature shown in Pl. C. Its extent and altitude are deduced very obviously from the experience of a large number of borings which are fully in accord in nearly every respect. In several wells the Sioux quartzite, with its unmistakable texture and pink color, was penetrated for a number of feet, and between the James River and Enemy Creek, near Mitchell and the Minnesota line, there are numerous exposures of the rock in the depressions which cross this old ridge. At Sioux Falls the typical Sioux quartzite was penetrated by a boring to a depth of 575 feet without reaching its base, and at a number of other points it has been penetrated to a considerable depth, as far out to the westward as White Lake. On the other hand, there is some evidence that in the Alexandria-Bridgewater-Salem region the quartzite is only a relatively thin film, and that it is underlain by sands and other beds.

The question as to whether or not in this case the Dakota sandstone and overlying formations abut against the underground quartzite ridge, or whether the quartzite is simply a locally hardened portion of the Dakota sandstone series, can not at present be settled. I saw a sample of the material, penetrated between 512 and 518 feet, from the boring in T. 104, R. 58, sec. 24, and found that it was a dark granite. This was at the base of the north side of the buried quartzite ridge above referred to, and would indicate that the quartzite is underlain by granite. In two county wells in the northern part of Douglas County granite was reported in a similar position on the opposite side of the quartzite ridge, but probably the identity of the rock is open to some question. The deep valley in the bed-rock surface lying north of the buried quartzite ridge is indicated by the fact that the Huron, Iroquois, Woonsocket, and Madison wells did not reach bed rock.

In the case of the Madison well the boring has penetrated to a point about 587 feet above sea level, and was discontinued in shale. The evidence of the line of borings from Brookings to Wolsey indicates some interesting features of underground topography in the bed-rock surface. In none of the borings is there definite evidence as to the nature of the rock penetrated—not even in the case of the De Smet well, which bored 410 feet into the rock. From Brookings to De Smet, as shown on the map, Pl. C, and in section 4 of Pl. LXXI, there is no doubt a regular slope of bed rock, as rock was not reached, so far as I know, by the 800-foot boring at Arlington. Thence to Iroquois there is a considerable acceleration in the slope, for no rock was reported in the bottom of the Iroquois well at 200 feet above sea level. At Huron—particularly at the Risdon well and in the deep Melville well—the maximum depth of the basins is indicated, west of which the bed-rock surface appears to rise rapidly to Wolsey. The authority for the occurrence of the rock in the Wolsey well at an altitude of 420 feet above sea level is Colonel Nettleton, who states in his "log" of this well that at 928 feet the boring entered very hard rock, into which it penetrated 2 feet. This would indicate the presence of a ridge which is terminated on the west by a steep slope, as shown by the deep wells around Miller and St. Lawrence; also to the south, as indicated by wells north of Wessington Springs, and to the east, as indicated by the deep wells around Huron, none of which reported bed rock.

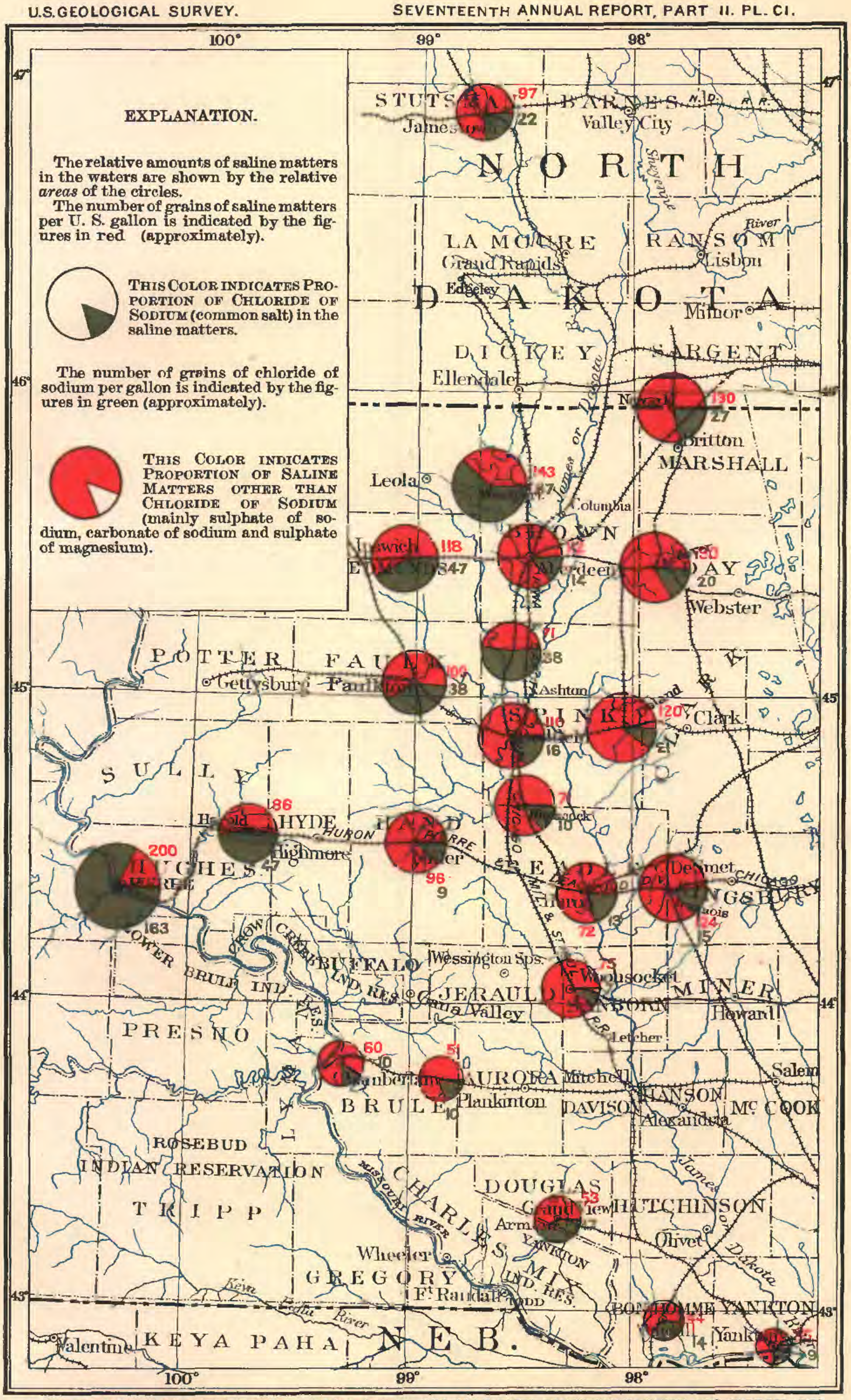
The presence and prolongation of this ridge to the northward is fully borne out by the experience of three wells north and northeast of Hitchcock. In two of these, the Budlong and the Glidden, quartzite was bored through and the granite entered for a short distance. In the third well, on the farm of Mr. Moxly, bed rock is reported at about the same altitude above tide level as in the Budlong well, but it was not penetrated, and its nature was not stated. I examined borings from both the Glidden and Budlong wells, and there could be no doubt as to the nature of both the quartzite and the granite as indicated in the logs in Pl. LXXIV and stated in the table heretofore given. The middle portions of the quartzite in the Budlong boring were not so distinctive in character as the upper and lower beds, for they appear to be of a somewhat softer material. The borings from the granite contained unmistakable feldspar fragments of jagged outline and in very fresh condition, together with some scales of mica and a large amount of quartz, mainly showing sharp edges. Some of the quartz grains were rounded, possibly by water action, but just as likely by the churning of the drill. It is also possible that some or all of these rounded grains were of sedimentary origin, but in this case undoubtedly derived from the overlying quartzite. It should be borne in mind in making a judgment on material of this character that there is more or less detachment of the overlying materials by the drill in both its descent and ascent, and by lateral chafing throughout the process of drilling. As the process of drilling in such a hard rock as granite is relatively slow, there is much more chance for admixture of material detached from above than in the case of rapid progress through soft beds.



MAP SHOWING CONTOUR AND ATTITUDE OF "BED ROCK" SURFACE IN A PORTION OF THE DAKOTA ARTESIAN BASIN. BY N. H. DARTON

SCALE: 0 5 10 20 40 80 MILES

JULIUS BIEN & CO. N.Y.



MAP SHOWING RELATIVE AMOUNTS OF SALINE INGREDIENTS IN SOME OF THE ARTESIAN WELL WATERS IN THE DAKOTA BASIN. BY N. H. DARTON

SCALE: 0 5 10 20 30 40 50 MILES

JULIUS BIEN & CO N.Y.

The precise course of this ridge, which passes north of Hitchcock, probably to Wolsey, and its relations to the adjacent slopes of the bed-rock floor eastward are not definitely known, but the experience of the Bohri well, near Raymond, and the absence of bed rock in the 1,200-foot boring at Clark indicate approximately the features shown in Pl. C. The Doland, Redfield, Ashton, Turton, Conde, Mellette, and Northville deep borings, which did not reach bed rock, indicate that it is not prolonged to the northward. The Bohri well penetrated supposed bed rock for 2 feet, but no report was given as to the nature of the rock except that it was very hard. The deepest boring at Aberdeen found the water-bearing beds and some underlying shales and sandstones underlain by 46 feet of quartzite lying on granite, which was penetrated 33 feet. This relation of the quartzite to the granite is in accord with the experience of the wells near Hitchcock. The position of bed rock in the Aberdeen well, in relation to that in the Hitchcock region, indicates a relatively gentle slope from the top of the Wolsey ridge to Aberdeen. To the east of Aberdeen there is but little evidence as to the nature and rate of the bed-rock slope, but the relations of the Groton, Andover, and other wells which did not reach it indicate that its rise is very gradual, as shown in section 2, Pl. LXXI, and by the contours in Pl. C.

The boring at Millbank, in which the granite was penetrated for some distance, and the surface outcrops of the formation in the Minnesota Valley below Ortonville bear out the idea of regular slope. The Brown Valley well appears to have reached the granite on this slope and penetrated it for a short distance. The material is not stated to be granite by Professor Winchell, but as part of the borings were "greenish, micaceous kaolinic clay or shale," and "white opaque and wholly unwater-worn angular quartz grains," it seems to me exceedingly probable that the material represented granite in at least the lower 40 feet of the boring. The well at Jamestown Asylum is reported to have penetrated the hard limestone for 19 feet at its bottom, and when we consider the general slope of the floor in the region south and east, I think there are fairly good grounds for considering this limestone to be either the Carboniferous or the Silurian bed rock which comes to the surface in Manitoba. The underground contours from Jamestown to Moorhead are constructed on this assumption, but, of course, it is evident that the edge of the limestone does not extend to Moorhead, where the deep boring passed through drift and possibly Cretaceous beds far into the granite. Some further light on the conditions in the slope from Jamestown to Moorhead are shown in fig. 59.

Returning to the southeastern corner of North Dakota, we find that the quartzite was penetrated in a number of wells, including Parkston, Scotland, Tyndall, Menno, and a well southwest of Parker. At Fort Randall the nature of the hard rock which was penetrated for 34 feet, according to Colonel Nettleton, is not stated, but presumably it was quartzite. The nature of the hard rock found in two borings at Elk Point is not known. The Ponca and Sioux City borings found the Carboniferous limestone underlying the Dakota water-bearing series, possibly with a thin, intervening representative of some intermediate formation. The Sioux City well penetrated a great mass of the limestone, then into some limestone and sandstone, through 15 feet of a hard, brown rock, which, according to Professor Todd, may be the Sioux quartzite, and then for nearly 550 feet into hard gray granite. The borings at Parkston, Menno, and southwest of Parker indicate that the buried quartzite ridge which is so prominent from near Mitchell to Sioux Falls sinks almost as rapidly to the southward as it does to the northward, and this slope is further delimited by the experience of borings near Parker and in central-western Turner County. The steep slope in the Canton region is indicated by the relation of the surface outcrops, the rapid increase of thickness of the Dakota and overlying Cretaceous sediments, and the experience of one or two borings in the southern part of Lincoln County. To the south of the steep southern front of the buried quartzite ridge there appears to be a relatively gentle slope intersected by two valleys, one of which heads near Menno, as indicated by the failure to reach bed rock in a 747-foot well, and by the relations of the wells in eastern Douglas County.

The irregular contour of the bed-rock surface, as shown in Pl. C, is no doubt due to subaereal erosion prior to the deposition of the Dakota sandstone. There is a possibility that the quartzite ridge which extends through Mitchell is a portion of the Dakota sandstone locally lithified, but as the evidence in regard to this is not yet conclusive, we may tentatively regard the ridge as a portion of the bed-rock floor.

PROSPECTS FOR WATER IN THE FLOOR OF THE ARTESIAN BASIN.

It is sometimes thought when sufficient water is not found in the overlying beds that increased supplies may be obtained by boring more or less deeply into the bed rock. This is a fallacy, for although in some instances waters have been found in the granite, and even in the quartzite, their occurrence is rare and can not be relied upon. The deep boring at Moorhead, in western Minnesota, is an instructive example. It was continued into bed rock contrary to the prediction of the State geologist that no water would be found, and it resulted in the waste of a relatively large sum of money. In the limestones and underlying formations in portions of North Dakota and in Iowa and Nebraska no doubt water supplies may occur, but it is useless to depend on finding them in the granite of the intermediate region.

COMPOSITION OF THE ARTESIAN WATERS.

The artesian waters of the Dakota basin are in all cases more or less saline, but in only a few instances are the mineral constituents in sufficient amount to affect the taste or general usefulness of the waters.

A quite extensive series of analyses has been made by Prof. James H. Shepard, of the department of chemistry in the South Dakota Agricultural College,[1] at Brookings, of the waters of South Dakota, and it is on these, together with analyses of the Newark, Jamestown, and Jamestown Asylum waters by other chemists, that I base the statements of this chapter. In the following table I have tabulated the principal constituents of the artesian waters:

Analyses of artesian waters of the Dakota Basin.

[Principal salts—parts per 1000.]

Locality.	Sodium chloride (common salt].	Sodium sulphate (glauber salts).	Sodium carbonate (washing soda).	Magnesium sulphate (Epsom salts).	Magnesium carbonate.	Calcium sulphate (gypsum or plaster of paris).	Calcium carbonate (chalk).
Yankton	.1643	.1172	....	.3160	....	.8700	.1246
Tyndall	.2438	.1002	....	.4036	....	1.1199	.0905
Armour	.2878	.1186	....	.5011	....	1.0550	.1554
Chamberlain	.1800	.3618	....	.4735	....	.8920	.1573
Kimball	.1688	.2211	....	.4834	....	1.0592	.1636
Woonsocket	.1128	.7941	....	.3701	....	.5360	.1630
Pierre	2.8052	....	.5711	....	.0050	....	.0771
Harold	.8029	.4550	.3817	....	.0575	....	.0286
Miller	.1501	1.2265	....	.2657	....	.1683	.2125
Huron	.2046	.6083	....	.4261	....	.6020	.1554
Iroquois	.2598	1.6153	.2432	....	.0353	....	.0195
Hitchcock	.1595	.6120	....	.4384	....	.6889	.1534
Faulkton	.6610	.7891	.3814	....	.0716	....	.0471
Redfield	.2626	1.5701	.0499	....	.0664	....	.0854
Doland	.3473	1.5091	.2057	....	.0512	....	.0230
Northville	.6396	.1620	....	.3988	....	.2280	.5580
Ipswich	.8089	.5076	.7079	....	.0557	....	.0239
Aberdeen	.2381	1.6538	.0108	....	.0811	....	.0879
Andover	.3308	1.6573	.2476	....	.0449	....	.0248
Westport	1.5031	.4177	.5175	....	.0386	....	.0200
Newark *a*	.4585	1.6500	.1422	....	.0262	....	.0774
Jamestown *b*	.3691	1.1394	....	.1542	....	.2490	.1880
Jamestown Asylum *c*	.3660	1.6424	....	....	.0511	....	.1446

a Analysis by H. E. Smith.
b Analysis by Prof. James A. Dodge, given by W. Upham, Glacial Lake Agassiz, p. 538.
c Analysis by Erastus G. Smith, Beloit College, as reported by Nettleton, loc. cit., p. 71.

At first glance it would appear that the constituents of these waters have no very definite distribution in relation to the location of the wells, except that in the southeastern corner of the State the waters are as a rule considerably purer than they are to the north and west.

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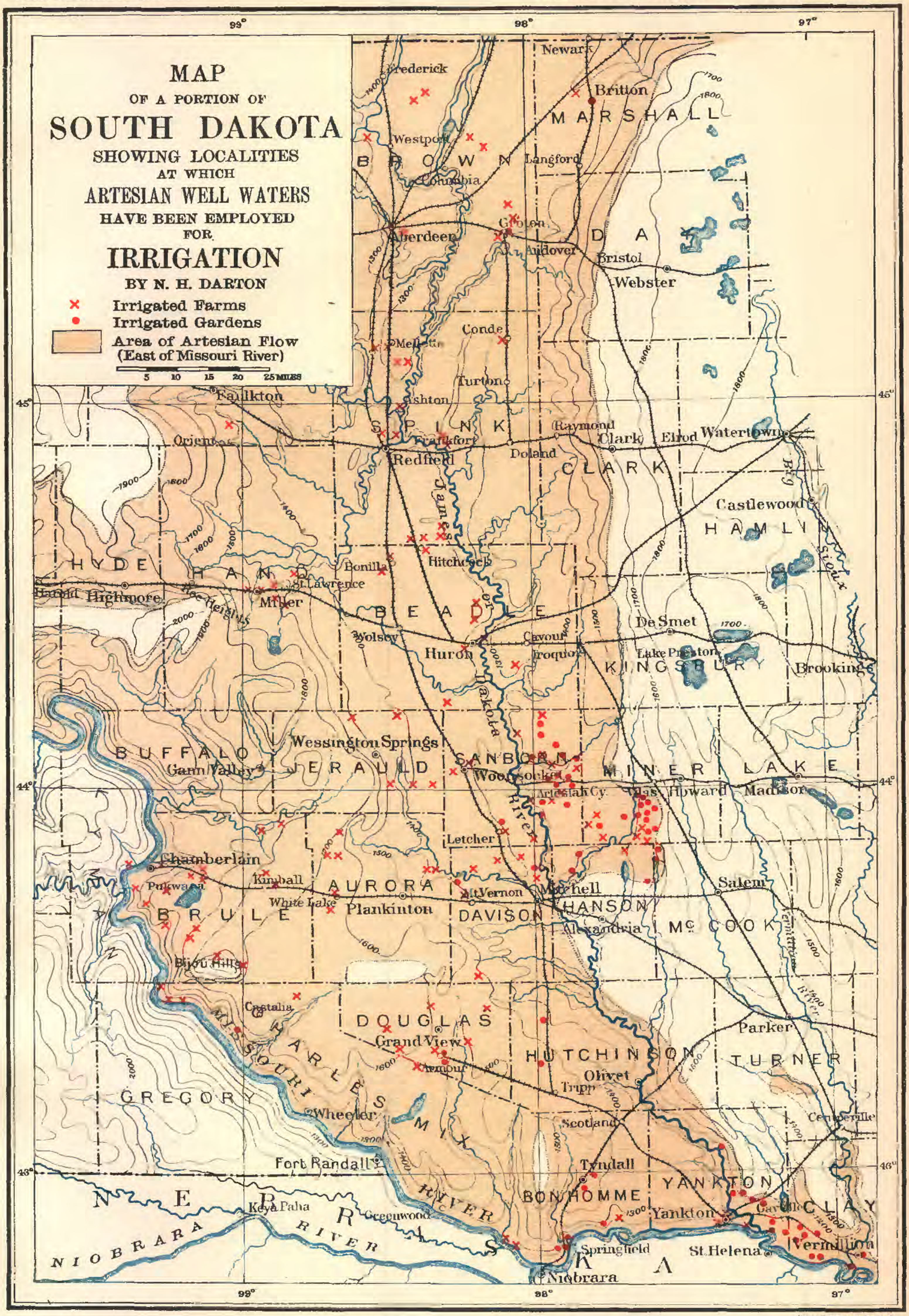
[1] Bulletin No. 41, January, 1895.

In order to bring out the principal features more graphically, Pl. CI has been prepared to show the relative amounts of the resoluble mineral ingredients in the waters of all the wells for which we have analyses, and also the proportion of sodium chloride, or common salt. The other resoluble saline ingredients, besides the sodium chloride, are mainly sodium sulphate, sodium carbonate, and magnesium sulphate, although there are other salts in small proportion in some of the wells. It will be seen from this map that the amounts of these soluble salts in the waters increase quite regularly from Yankton northward over a wide belt as far as the latitude of Woonsocket, remain almost stationary in a narrow zone along the James River Valley, and increase gradually both to the east and west on either side of this valley. The large amount at Pierre is anomalous, and the amount at the well west of Westport is rather exceptionally large. Professor Shepard, in his discussion of his analyses of the waters of the South Dakota wells, arrived at the conclusion that the more highly saline waters were those from a "first flow," and that the second-flow waters were materially purer. I have considered this view with some care, and can not say that I am strongly impressed by it. It is certainly the case with some of the wells, but with other wells first-flow waters have proved to be much purer than would be expected in accordance with the hypothesis, and for a number of other wells the evidence as to the identity of the flow and the relative amount of mineral constituents that it contains is not sufficiently definite to sustain the hypothesis.

The increase in purity of the artesian waters along a line from Chamberlain through Kimball, Armour, and Tyndall to Yankton, is thought to be due in all probability to the fact that the water-bearing beds are particularly porous in this area and in the course along which large volumes of water flow southeastward to their outlets in the outcrops of the Dakota formations below the mouth of Big Sioux River. The coarseness of materials and large volumes of water are facts observed in the wells along this line. To the northward there is the underground ridge of quartzite which appears to impede the southward flow of the underground waters in the region north of Mitchell. It is thought that the increased amount of mineral constituents in that direction is due to a more sluggish circulation of the underground waters, so that less of the original mineral ingredients in the rocks have been removed and the waters have a longer time to take them into solution. This is also the case in eastern North Dakota, where the Dakota sandstones appear to be finer grained on the whole and the circulation and outlet of the waters are probably much less in volume than along the line from Chamberlain to Yankton. The very large amount of saline constituents in the well at Pierre is no doubt due to some local cause, such as an increased amount of saline material in some local basin in the water-bearing beds. The waters at Edgeley, judging by the taste, are equally saline, and their salinity is probably due to a similar cause.


MAP
OF A PORTION OF
SOUTH DAKOTA
SHOWING LOCALITIES
AT WHICH
ARTESIAN WELL WATERS
HAVE BEEN EMPLOYED
FOR
IRRIGATION
BY N. H. DARTON
Irrigated Farms
Irrigated Gardens
Area of Artesian Flow (East of Missouri River)
5 10 15 20 25 MILES
BROWN
MARSHALL
DAY
SPINK
CLARK
HAMLIN
HYDE
HAND
BEADLE
KINGSBURY
BUFFALO
JERAULD
SANBORN
MINER
LAKE
BRULE
AURORA
DAVISON
HANSON
McCOOK
DOUGLAS
HUTCHINSON
TURNER
CHARLES MIX
GREGORY
BON HOMME
YANKTON
CLAY
NEBRASKA
NIOBRARA RIVER
MISSOURI RIVER
James or Dakota River
Big Sioux River
Vermillion River
Aberdeen
Huron
Mitchell
Yankton
Redfield
Chamberlain
Watertown
Brookings
Plankinton
Wessington Springs
Woonsocket
Faulkton
Highmore
Miller
Madison
Howard
De Smet
Salem
Parker
Olivet
Tyndall
Springfield
Vermillion
Fort Randall
Niobrara
99°
98°
97°
45°
44°
43°

ORIGIN OF THE ARTESIAN WATERS.

There has been considerable speculation as to where the waters pass underground, but most geologists agree that the waters in the Dakota beds pass beneath the surface in the elevated regions adjoining the Black Hills and Rocky Mountains. In these regions the Dakota beds are upturned and reach the surface, so that they are accessible to the waters over considerable areas. In these outcrops the formation consists of sands and porous sandstones, and much of the water that comes in contact with them is absorbed. The underlying formations are also more or less permeable, particularly the limestones, which are often cavernous, so that beneath the great mantle of clays lying above the Dakota beds there are receptacles for large bodies of water, which, when they once have passed underground, are kept down by these impervious overlying materials. Although studies of individual streams in their passage across the Dakota and underlying formations in the Black Hills and Rocky Mountains have not in every case yielded definite results as to the amount of the water which sinks, yet it is clearly apparent that many of the streams greatly diminish in volume before they pass out under the plains. In the Black Hills this is conspicuously the case with Rapid, Box Elder, and Spring creeks, and in the foothills of the Rocky Mountains there are many similar examples. As these waters enter the Dakota beds at altitudes upward of 3,000 feet above sea level, we can readily understand the reason why the pressure is so great when they are tapped by wells in the relatively low lands eastward.

I have indicated in Pl. CII some of the general conditions which are supposed to be involved in the question of the origin of the waters in the Dakota sandstone. The principal features indicated are the out crops along the uplifts of the Black Hills, Big Horn Mountains, Front Ranges of the Rocky Mountains, and some minor areas. In all of these outcrops the Dakota sandstone is exposed over areas of greater or less width, together with the underlying sedimentary formations, which lie on a surface of granite and other crystalline rocks. The sedimentary formations are all more or less permeable to waters, and this water is free to pass to the eastward under the plains region. In the surface outcrops westward not only are there extensive areas in which more or less of the rainfall may sink directly, but the outcrops are crossed by streams of greater or less size, portions of which, it is thought, sink into permeable sedimentary beds. This is notably the case with the Missouri River at Great Falls, the Big Horn River on the northern flank of the Big Horn Mountains, and both branches of the Cheyenne in the ends of the Black Hills uplift. Accordingly, I have also indicated on Pl. CII the watershed area of streams which pass over Dakota sandstone or underlying permeable beds on their way eastward. There is also shown on this plate the outcrop area of the Dakota sandstone and underlying Carboniferous limestone in the Missouri Valley from the southeastern corner of South Dakota southward. The map indicates the contour of the entire region under discussion, and I have also indicated the altitudes in round numbers of important points along the outcrop zones. It will be seen that these altitudes vary to the westward from 3,200 to over 7,000 feet, and from 1,100 to 1,300 to the eastward, where the waters are more or less free to escape at the surface. The zone of eastern outcrop of the Dakota sandstone extends northward through the northeastern portions of South Dakota and the eastern margin in North Dakota, but it is there so deeply buried beneath glacial drift and lake beds that I have not attempted to represent its location. There are also some detached areas in the western portion of the State of Minnesota.

THE AMOUNT OF THE WATERS.

It has been found almost impossible to make any definite calculation as to the total water resources of the Dakota formation in the area to which this report relates. We do not know how much water passes into the beds in their outcrop areas westward, and we can not compute the amount that escapes to the eastward in surface springs in the outcrop area of the formation. Calculations based on the features shown in Pl. CII give for areas of outcrops of permeable beds 2,400 square miles in the Black Hills, 7,000 in the Big Horn Mountains, over 3,000 in the Rocky Mountain foothills in Montana, and about 1,500 in the Rocky Mountain foothills in Wyoming.

Too few wells have as yet been sunk to throw any light whatever on the total amount of water that the formation may be expected to yield. The present outflow of all the wells can be but a small proportion of the intake of the beds at their outcrop at the very lowest estimates. This is quite clearly shown by the exceedingly slight influence in pressure that the wells have upon one another in areas where there are many wells quite near together. In some cases a well has been considerably influenced by another well sunk within a few feet or yards of it, but this would not indicate a limit to the total capacity of both.

It has been claimed by some persons that the pressures and yields of many of the wells are decreasing, but of this I can find no definite evidence that would indicate diminution in the water supply. Diminished yields are usually known to be due to clogging of the pipe, caving of the roof of the chamber from which the artesian flow has been taken, escape of flows along the outside of the tubing, or the growth of an incrustation over the perforations at the end of the tubing. In some of the most notable cases of wells in which the volume and pressure have decreased the recent sinking of other wells in the immediate vicinity or the cleaning out of old wells has increased the original pressure and volume. I see no reason why the artesian waters should not be produced in sufficient volume to supply all local needs of the usual kind and irrigate in a moderate way all lands to which their head will carry them. I believe there are no grounds for fear that the water supply will give out or prove inadequate for every need. There are, it seems, wide areas which are too elevated to be reached by artesian flows, but large volumes of water will rise even under these part way to the surface, onto which they may be pumped by windmills and other economical means.

ARTESIAN IRRIGATION.

GENERAL STATEMENT.

The use of artesian waters for irrigation in the Dakotas began several years ago, and it has been gradually growing ever since. There are now nearly 100 farms on which artesian waters are used for irrigation on a greater or less scale, not counting many gardens and several trial areas. This irrigation has been practiced throughout the artesian area, but mainly in South Dakota. In most cases the results have been so satisfactory that much interest and enthusiasm on the subject has been aroused, and this is now spreading rapidly among all the more progressive farmers of the region and to those who are interested in farm investments in the State. Many wells were sunk specially for irrigation in 1894, and a still greater number were sunk during the past year. I have indicated in Pl. CIII the localities at which irrigation has been tried with satisfactory results, both on farms and in gardens, so far as it has been possible to obtain information.

As irrigation of any kind requires skill and experience in order to obtain the best results, its progress in the State has necessarily been slow. Many farmers have learned by experience how to use the waters, and a number of successful farms have served as object lessons for all who are interested in learning the art. Some of these farms have had the very great advantage of the superintendence of expert irrigators who have had long experience, or the fruits of the experience of others, in other portions of the West. Unsuccessful attempts at irrigation with the artesian waters have, so far as I can find, been invariably due to excessive flooding, in most cases when the crops were growing, or to the use of cold waters from shallow wells. Two important questions have been raised regarding artesian irrigation. One relates to the quality of the waters, and the other to the quantity.

It is claimed by some that the waters containing large amounts of mineral constituents, or at least of certain mineral constituents, will prove deleterious to plant growth, and that if the plants are not affected by this influence with the first few floodings the minerals will eventually accumulate in the soil and render it unfit for plant growth. However plausible this may seem, it does not appear to be borne out by the experience of the irrigators. Waters containing considerable amounts of saline ingredients have been in use on many gardens and farms for several seasons, and they do not appear to have in any way diminished the growth of the plants by poisoning the soil. It should also be borne in mind in this connection that many saline ingredients which the chemist finds in the waters are plant foods, and are really of great assistance in fertilizing the soil. It can not be claimed that all the artesian waters of the region will prove acceptable for irrigation, but it does appear probable that waters unfit for this use will be found to be very unusual. One of the most saline waters in South Dakota flowed from the well at the Indian school at East Pierre, and this was used on a garden for two seasons with great success. I have recently learned that the very saline water from the Devils Lake well in North Dakota has been successfully employed for irrigation.

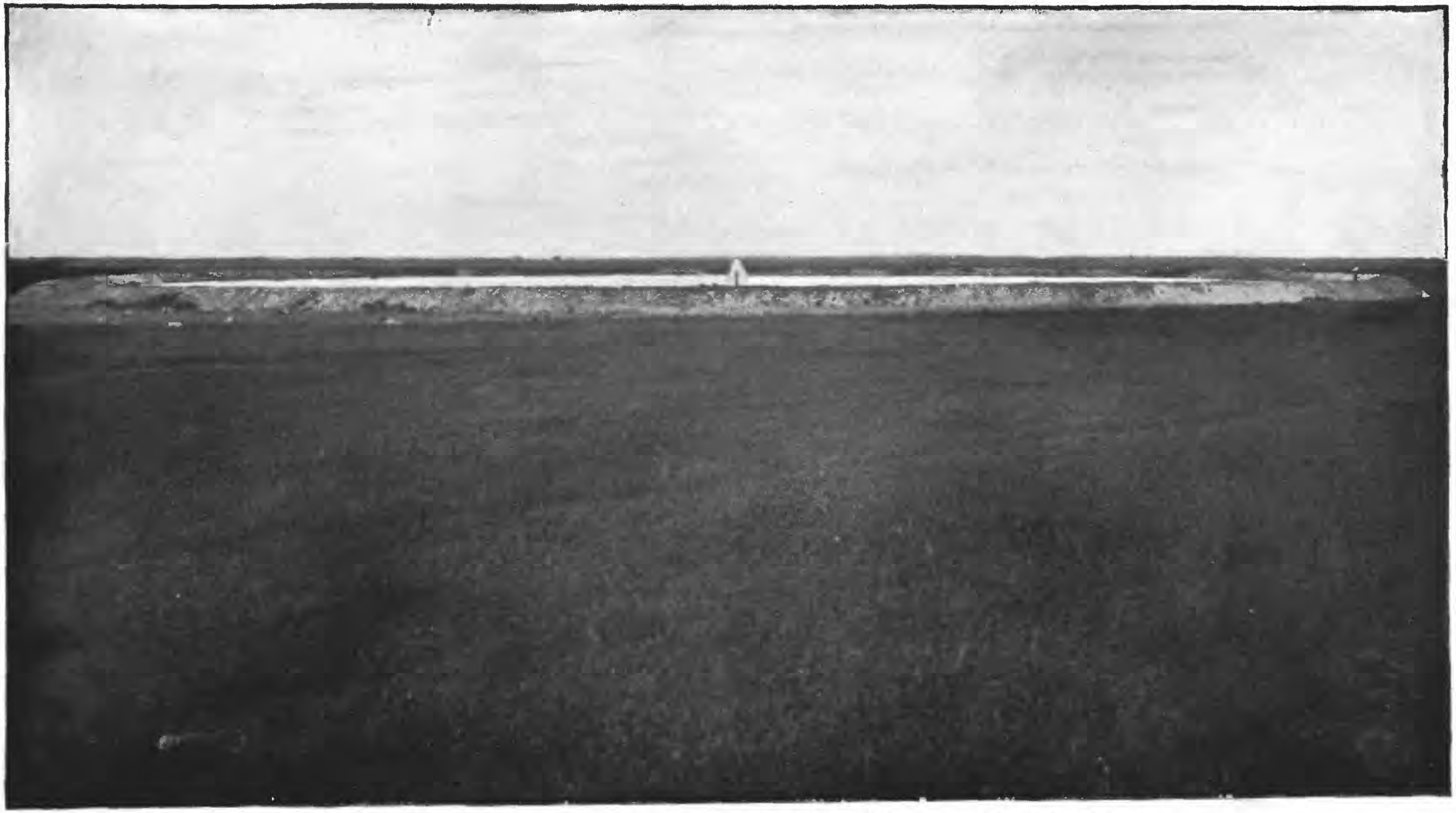
In regard to the quantity of the water, I think there need be no apprehension. After a careful consideration of the probable source of supply and conditions of transmission of the water, it appears almost certain that enough water may be obtained from underground sources to flood all of the region to which the head of the water is sufficient to afford a flow. It should of course be understood that this does not provide for any great waste of the waters, but is based on the supposition that the entire outflow of the well will be economically applied to irrigating the soil on which the crops are to be raised. The estimate is based largely on the experience of wells which are sunk in groups or in the vicinity of one another. We find in these cases that the volume of water has not been materially affected by the number of outlets. This has not as yet been put to a very severe test, but at the same time, if the volume were small, wells near together would affect the flow of one another very noticeably.

AURORA COUNTY.

In this county there are a number of artesian wells which were sunk for irrigation, and other wells are in progress or projected for this use. All trials of artesian-well irrigation have been entirely successful, and great confidence exists as to the possibility of successful farming with artesian waters.

The Mullen brothers, with a well 950 feet deep, irrigated 40 acres in 1895. The gross sales from 19 acres of vegetables were $2,200. Eight acres of potatoes yielded 960 bushels, and 1 acre, irrigated twice, produced 300 bushels; beets, 20 bushels per acre; wheat, 32 bushel per acre; 7 acres onions, 1,800 bushels; and cabbage, 3,000 heads from three-fourths of an acre. Several other irrigators were similarly successful.

Extensive plans have been developed for irrigation in the season of 1896 in various portions of the county. The configuration and altitude of the county of Aurora are such that irrigation will be practicable over very nearly all of its area. In the extreme northwestern corner of the county, and possibly also along its southern border, there may be a few very small areas that are too elevated for artesian flow, but this is thought not to be probable.



GENERAL VIEW OF RESERVOIR AND WELL ON RICHARDS'S IRRIGATION FARM, NEAR HURON, SOUTH DAKOTA.

VIEW FROM BANK OF RESERVOIR ON RICHARDS'S FARM, NEAR HURON, SOUTH DAKOTA, SHOWING DITCH AND IRRIGATED FIELDS.

BEADLE COUNTY.

Irrigation with artesian water has been practiced in this county for several years past, but on only a few farms. The results have been eminently successful, and they have afforded encouragement to many persons in adjoining regions. The configuration of the region is very favorable for irrigation, and a large supply of water under great pressure throughout the county renders the conditions all that could be

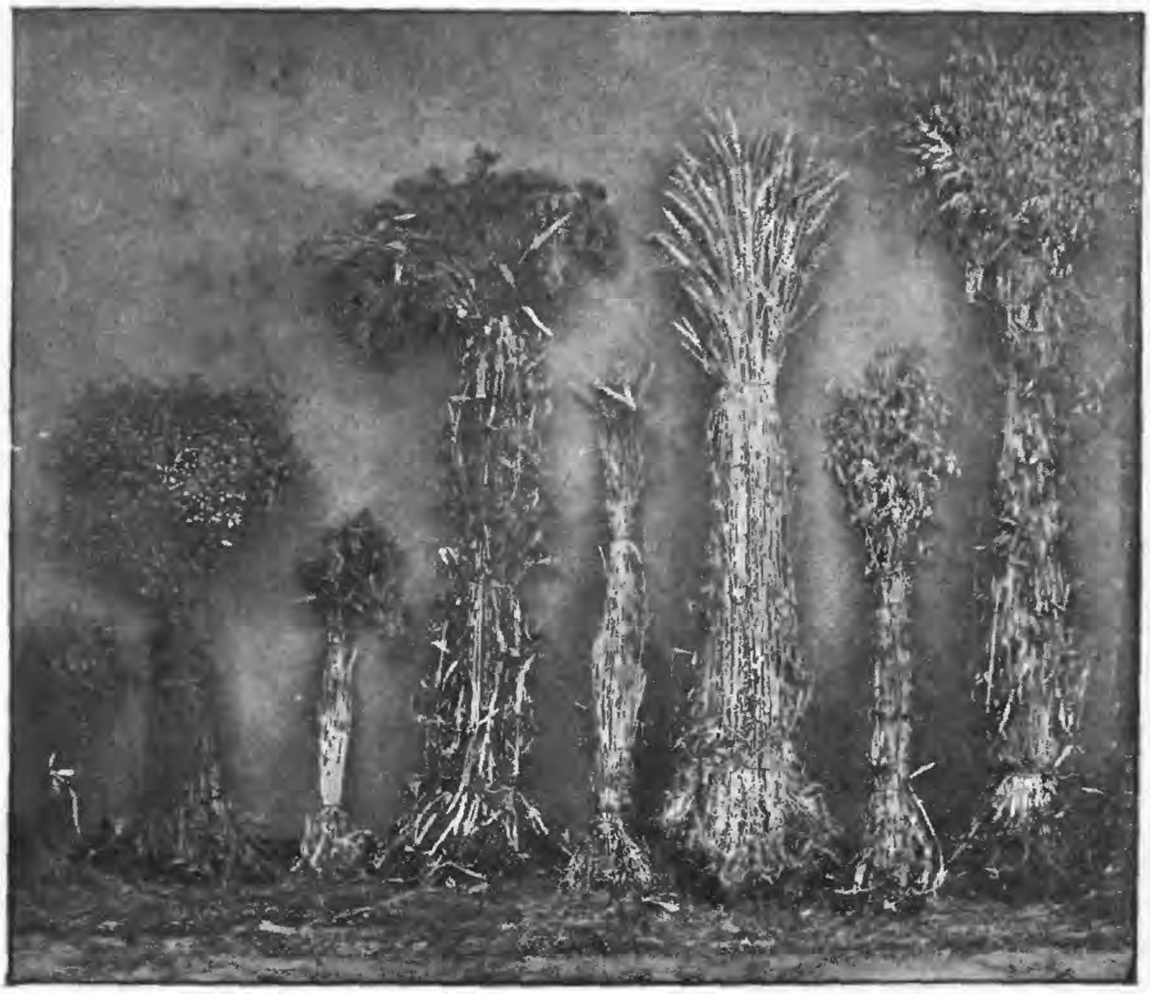


FIG. 64.—Results of irrigation on Richards's farm, near Huron, S. Dak. Shows samples of certain nonirrigated and irrigated crops. The larger bunch of each pair was irrigated. From a photograph kindly furnished by Mr. Richards.

desired. The principal operations have been in the vicinity of Huron, where there are several irrigation farms. Some results obtained are as follows: T. A. White, about 3 miles northwest of Huron, reports a very large production of irrigated crops. His beets averaged at the rate of 2,480 bushels per acre; corn, about 50 bushels; onions, 500 bushels; rutabagas, 846 bushels: sugar corn, 1,000 dozen; squashes, over 4,000; potatoes, 175 to 200 bushels; cabbage, 4,000 heads; and pumpkins, from 2,000 to 2,500. His land has been irrigated for the past three seasons. Several other crops also produced abundant returns, notably beans, melons, corn, pop corn, and a hedge of cottonwood trees.

Mr. J. H. Nusser, near Cavour, irrigated 14 acres from the township artesian well. His results were as follows: Corn, 65 bushels per acre; 3 acres of onions yielded 1,300 bushels; 2½ acres of cabbage yielded 15,000 heads; 3 acres of potatoes yielded 100 bushels to the acre; and large yields of squashes, melons, beets, and cucumbers. Mr. T. S. Everitt, of Hitchcock, was not able to irrigate as fully as desirable, but reports that he was well pleased with the results. Wheat yielded 25 bushels per acre; oats, 50 bushels, and barley 50 bushels. His well is 909 feet deep, reservoir 15 acres, with 5-foot banks and 6 miles of main ditches. He expects to irrigate 1,000 acres of grain in 1896. R. D. Richards, of Huron, reports that on his farm, north of Huron, 107 acres were irrigated in 1895. Ten acres yielded 400 bushels of corn; 90 acres of wheat yielded 2,200 bushels of No. 1; 5 acres of oats yielded 350 bushels; 2 acres of potatoes yielded 400 bushels. This was all in a dry season, in which unirrigated crops were in most cases very scant and often complete failures. Mr. M. O. Besserud, near Cavour, irrigated about 20 acres of land in 1894, and raised wheat, oats, barley, corn, potatoes, and garden truck. His wheat yielded over 33 bushels per acre; oats, 50 bushels; onions, 250 bushels; potatoes, 86 bushels; and barley yielded 42 bushels. The relatively low yield of potatoes is claimed to be due to poor seed. One acre planted with seed of better quality yielded about 200 bushels. Barley not irrigated yielded 4½ bushels per acre.

Mr. T. A. White reported that in 1894 his irrigated fields yielded as follows: Corn, 52 bushels per acre; onions, 360 bushels; pop corn, 50 bushels; squashes, 1,200 well matured, and many others which were fed to hogs or cows; pumpkins, 900 well matured; sugar corn, 1,200 dozen; and onions and cabbage in large crops. The total receipts from the irrigated tract in 1894 were over $2,000. Mr. F. C. Ward, 2½ miles southwest of Huron, had in 1890, 20 acres of wheat, 5 of millet, 4½ of oats, and 10 of flax.

BONHOMME COUNTY.

Relatively little irrigation has been done in this county so far, but several very satisfactory experiments have been made, both in gardens and farms, and there are a number of farmers who intend to irrigate quite extensively next season. The greater part of the area of the county lies favorably for irrigation, and is underlain by abundant supplies of waters with sufficient head to carry them over the surface, excepting possibly in one or two restricted areas on the highest elevations. In the vicinity of Tyndall, Mr. C. M. McCollum irrigated 30 acres in 1895, mainly in corn, of which the yield was 1,050 bushels. One acre of potatoes also afforded a large crop. The ground was well watered the previous winter, but not irrigated subsequently. About Springfield a number of persons have irrigated gardens of greater or less size and fruit trees with most satisfactory results. At the

Hutterische Brüder Society considerable irrigation has been tried, mainly for cabbage, sorghum, and potatoes, with most encouraging results. Several wells were sunk for artesian irrigation in 1895, or are now in process of sinking. Two of these are at the mouth of Choteau Creek, and another is on the farm of John Brown, near Springfield.

BROWN COUNTY.

Irrigation has been tried on various scales at a number of points in this county with very satisfactory results. Owing to the clogging of some of the wells which furnished the water supply, relatively little irrigation is now in operation, but it is expected that in the season of 1896 a fairly large acreage will be irrigated. One of the farmers who irrigated in 1895 was Mr. W. A. Burnham, at Groton, who had about 20 acres under cultivation. It is reported that his wheat produced about 35 bushels per acre and his barley 63 bushels per acre. The entire area of Brown County has a favorable configuration for irrigation, and it has ample supplies of underground waters throughout.

BRULE COUNTY.

Very great activity has been displayed in this county in the application of artesian waters to irrigation. Over 20 wells have been sunk for irrigation, either by townships or individuals, and others are in progress or projection. On the farms which have already been irrigated most satisfactory results have been obtained, and the prospects for extensive farming by irrigation are particularly promising. Nearly the entire area of the county is within reach of artesian flows, and much of the land has a favorable configuration for irrigation.

Mr. Claus Arp, in township 102, range 71, has been irrigating from an artesian well for two seasons with complete success. Mr. Henry Willrodt, of Ola Township, finished his well too late in the spring to be able to utilize the water to the best advantage, but, notwithstanding, his wheat yielded 30 bushels per acre, oats 70 bushels, corn 50 bushels, and potatoes 170 bushels. Mr. W. A. McKellerick, of Willow Lake Township, irrigated 4 acres of wheat from a township well, and his product thrashed 150 bushels, of which he claimed the grains were as large and plump as peas. L. Wait, of the same township, used water on 4 acres of wheat with similar results. John Houser, of Ola Township, irrigated 2 acres, which yielded 40 bushels of wheat to the acre. J. J. Gregg, near Lyonville, irrigated 20 acres from a township artesian well; 8 acres of corn yielded 480 bushels, and 10 acres of wheat yielded 215 bushels. H. L. Willrodt, township 102, range 71, irrigated 165 acres from his own artesian well, and reports that 90 acres of corn yielded 50 bushels per acre; 40 acres of wheat yielded an average of 30 bushels per acre; 15 acres of corn yielded 1,080 bushels in all, and 5 acres of potatoes yielded 50 bushels. Fifteen to twenty farmers in the county outside of those mentioned used waters from township wells, and in all cases obtained most satisfactory results. There are extensive plans for developing the waters in this county next year. Wells are being sunk, reservoirs built, ditches dug, and all arrangements made for intelligent irrigation. Some of the farms are of great acreage, and the farmers expect to make large profits from their crops of the coming season. Practically no crops were raised in this county in 1895 without the assistance of irrigation.

CHARLES MIX COUNTY.

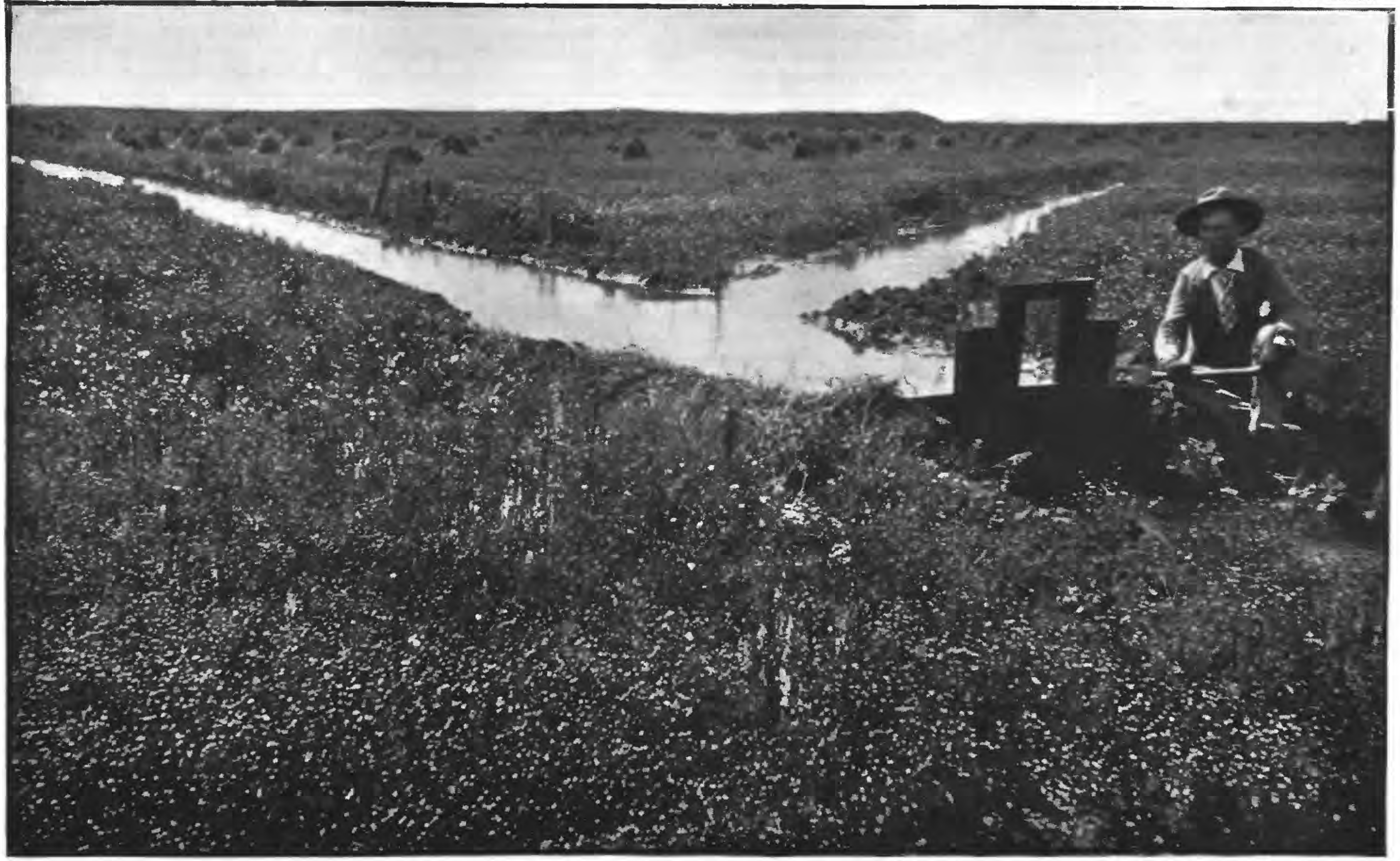
In the western part of this county some trials have been made of artesian irrigation, and the results have been so satisfactory that extensive operations will be carried on during the coming season. Mr. O. Turgeon, near Castalia, has irrigated from an 8-inch well having a depth of 586 feet. In 1895 he tried the water on 90 acres of corn, and just before harvest estimated that the yield would be 6,750 bushels. Considerable hay land and garden were irrigated with excellent results. The Hammer well has been used for irrigating gardens, and waters from the new artesian wells of Watson Ham, George Rhodes, W. B. Wood, and Chris. Singer have all been used for irrigation with satisfactory results. Mr. Rhodes reports a harvest of 1,200 bushels of corn from 23 acres and 100 bushels of potatoes to an acre.

DOUGLAS COUNTY.

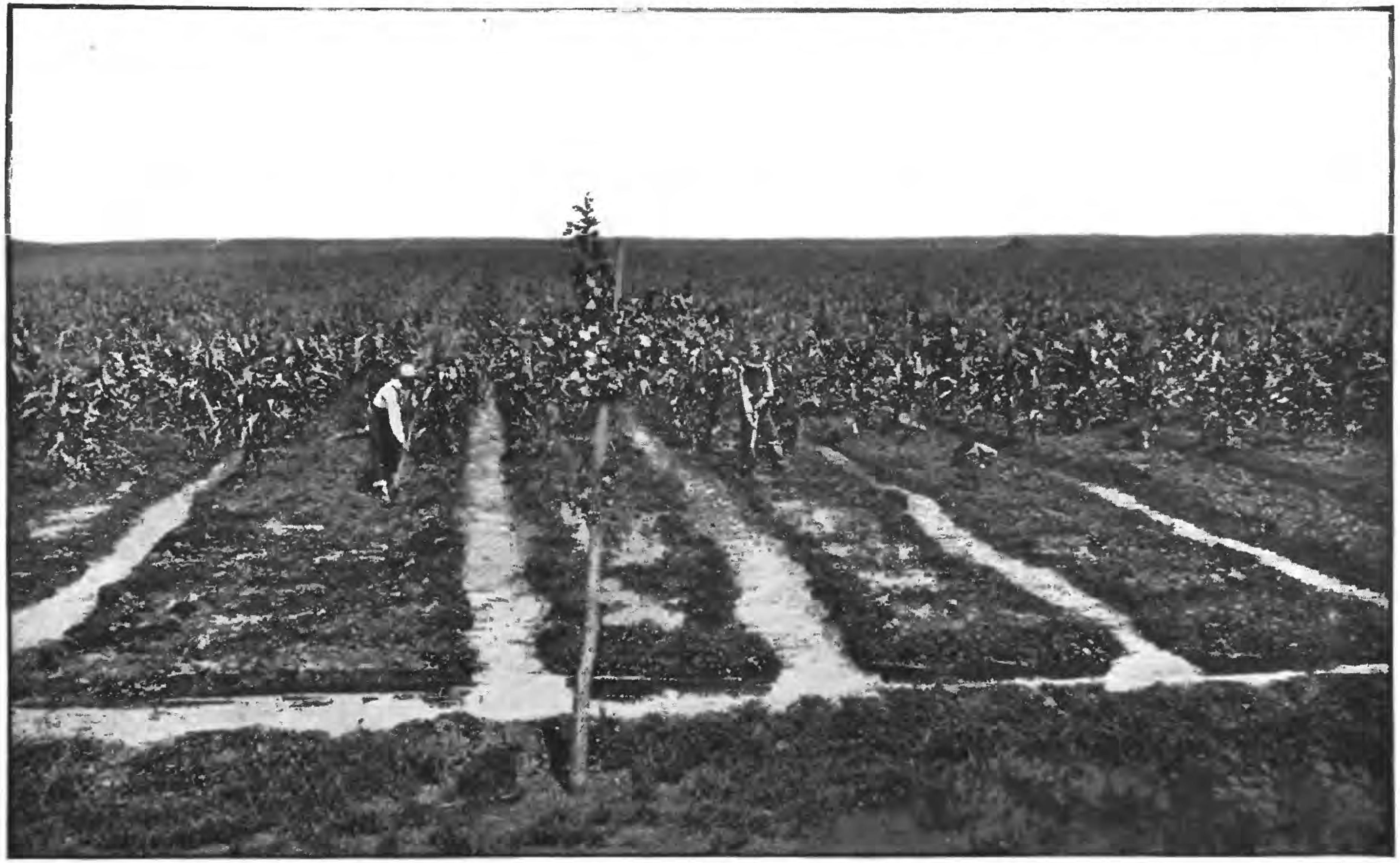
The farmers of Douglas County have become greatly interested in artesian irrigation, and during the past year several successful trials were made. The configuration of the county is such that irrigation is practicable at nearly every locality, and water supplies under considerable pressure appear to underlie the entire region. One farmer used water from the county well in township 99, range 65, and a trial acre of wheat yielded 111 bushels. The average crop in the vicinity on land not irrigated was 15 bushels. Mr. L. W. Wheelock, near Armour, had very successful results with corn, oats, and potatoes. On one area only partially irrigated 44 bushels of oats per acre were raised, and on similar land near by without irrigation only 14 to 18 bushels per acre were obtained. He is planning to irrigate extensively next season. In Armour many persons have used artesian waters in gardens with excellent results. Mr. J. A. Wilson, northeast of Armour, has irrigated 200 acres, and next season will have 640 acres under irrigation. A number of persons in the vicinity of county wells have tried the waters to a greater or less extent, and next season these waters will be extensively used.

HAND COUNTY.

The principal operations in this county have been in the vicinity of Miller and St. Lawrence, where a number of very successful trials have been made during the past two seasons. The results have been so



VIEW OF DITCHES, WATER GATE, AND IRRIGATED FIELDS ON THE RICHARDS FARM, NEAR HURON, SOUTH DAKOTA.



VIEW ON RICHARDS'S IRRIGATION FARM, NEAR HURON, SOUTH DAKOTA.

encouraging that the operations will be extended considerably in 1896. Waters from the township wells have been used in greater part. Excepting in the highlands about Ree Heights, practically all the area of Hand County appears to be within reach of artesian flows and to have soils and topographic configuration suitable for artesian irrigation.

JERAULD COUNTY.

Some progress was made with irrigation by artesian waters in this county last season, and in 1896 six or seven farms will be irrigated. Mr. Frank Campbell, in township 106, range 63, has a well recently completed and is building a reservoir to hold 5,000,000 gallons. Mr. S. H. Abert, township 108, range 65, has a 4-acre reservoir and plans to irrigate 500 acres. Mr. F. B. Brayton reports that on his farm, near Alpena, excellent results have been obtained. Oats wet in May, 1895, yielded 60 bushels to the acre; barley yielded 20 bushels, and cabbages, tomatoes, and potatoes yielded large crops. On land in the vicinity which was not irrigated the oats crop averaged 20 to 23 bushels per acre.

MARSHALL COUNTY.

Relatively little has been done in irrigation in this county, but several farmers have planned to use artesian waters next season. A well has been sunk at Burch for artesian irrigation, and the waste waters of the mill at Newark will be employed for irrigation. They now flow into a lake 100 acres in extent and from 4 to 8 feet deep. Trial tests in a garden have yielded most satisfactory results. All the lower lands of this county are suitable for irrigation and have large supplies of excellent waters underlying them at a depth averaging about 1,000 feet.

MINER COUNTY.

Artesian waters from the relatively shallow wells of this county have been used to some extent for the irrigation of gardens and small areas of farming land. In most cases the results have been very satisfactory, but on account of the small flows and low pressures of the waters in the shallow wells an impression prevails that irrigation on a large scale would prove too expensive for general adoption. As flowing wells are obtainable only along the western margin and in the southwestern corner of the county, irrigation operations have been confined to this area. In the northeastern portions of the county, where flows are not obtainable, irrigation will, of course, be attended by the disadvantage of having to pump the waters, and in some areas the supplies in pump wells are inadequate for irrigating large areas. The deep-seated waters of the Dakota formation, which underlie a narrow belt in the western portion of the county and an area of considerable size southwest of Vilas, have not been thoroughly tested for water supply. These waters will probably prove more serviceable for irrigation than those from the shallow wells, for their pressure is sufficiently great to carry them to reservoirs so elevated as to be capable of flooding wide areas. Farmers in this county who have reported the results of irrigation are Mr. C. O. Bryan, near Epiphany; Mr. Peter Cadmus, near Vilas; Mr. J. N. Briggs, near Miner, and Mr. John Patterson, near Canova. The wells average from 150 to 165 feet in depth, 2 inches in diameter, and range in flow from 5 to 50 gallons per minute.

SANBORN COUNTY.

Considerable artesian-well irrigation has been practiced in this county, especially in gardens, and the results have been so satisfactory that the use of the waters is rapidly increasing. The waters of the smaller wells of the shallow artesian area in the eastern portion of the county have been used by many for irrigating gardens and small fields with most gratifying results. In a few instances the waters were used in too large amount or at too low a temperature, and in these cases the results were often unsatisfactory. The waters of the deeper wells have been used for farm irrigation at several localities. Mr. G. W. Crawford, near Letcher, used water from the Letcher artesian well and obtained large crops of onions from a relatively small area. Mr. Ryan, near Letcher, has irrigated for two seasons with satisfactory results, and is constructing a 2-acre reservoir to extend his operations. Some irrigation has been done with the waters of the Woonsocket well with satisfactory results. The entire area of Sanborn County is underlain by water-bearing Dakota beds at depths of from 550 to 850 feet, which will furnish waters in sufficient supply and with adequate head to irrigate its entire area. The shallower waters in the chalk and at the base of the drift and in the eastern portion of the county often have sufficient head to flood wide areas where the land is less elevated, but on some of the higher areas they have insufficient pressure to fill reservoirs for extensive irrigation. Of course, they could be raised by windmill or other pumping, and by these means be made available. The shallow waters are too cool for direct application to the land, but by lying exposed to the air in reservoirs this would soon be remedied.

SPINK COUNTY.

Extensive trials of irrigation by artesian waters have been made in this county on several farms, mainly under the supervision of experienced irrigators. These farms have served as object lessons to many visitors who are interested in artesian irrigation, and have done much toward establishing the conviction that artesian irrigation can be successful. The two most notable farms are the Hunter farm, near Mellette, and the Hassel and Myer farm, near Redfield. Besides these, a number of farmers have used artesian waters with success. Mr. George A. Peterson, near Northville, in the season of 1894 irrigated 32 acres of land with fair results. The crop was wheat, and the water was put on rather too late for best advantage, and on some portions of the area too much was used.

Mr. F. O. Child, at Ashton, reports the results of his experience with irrigation by waters from the well at the mill at Ashton. His operations were not extensive and the waters were not used to the best advantage, but the results with wheat, millet, sugar corn, grass, and garden truck were excellent. On the Hunter farm, 2 miles south of Mellette, the crops for 1895 have been very large. About 400 acres were irrigated, of which 70 were devoted to corn, 42 to wheat, 44 to oats, 200 to potatoes, 20 to flax, 20 to millet, and an extensive tract to 3,000 varieties of vegetables and experimental plants. The oats averaged 78½ bushels per acre; wheat, 34 bushels, grade No. 1; early corn, about 35 bushels; potatoes, 300 bushels in cultivated land, but where the ground was hardened they went only about 90 bushels per acre. The millet was very fine and is estimated at about 3 tons per acre.

This farm is supplied by a well 1,065 feet deep, with a flow of 1,200 gallons per minute, and a circular reservoir covering 5 acres. There are 3 miles of main ditches, and suitable facilities for flooding the land rapidly. The wells around Redfield have supplied waters for irrigation to a number of farmers, and where the irrigation had been properly managed the crops were all very large. The Hassell and Myer farm continues to obtain most satisfactory results from irrigation and to furnish a most instructive object lesson to visitors seeking information as to the means and results of artesian-well irrigation. One hundred and sixty acres were irrigated; 5 acres of wheat yielded 202½ bushels; 30 acres of oats yielded 2,250 bushels; 48 acres of potatoes yielded 7,200 bushels; 30 acres of barley yielded 1,800 bushels; and cabbage, onions, beans, flax, and millet yielded large crops. Fifteen acres of meadow timothy yielded 2½ tons of hay. In this region on lands not irrigated the crops were generally very poor. Mr. A. J. Stevens raised 700 bushels of potatoes on 5 acres of land, and had large yields of squash and cabbage. One acre of onions yielded 450 bushels.

Mr. F. W. Hagmen raised 399 bushels of wheat on 10½ acres of land irrigated by water from the Hassel and Myer well.

J. M. Miles, Redfield, reports most satisfactory results this season on land irrigated last year. One of the most remunerative products was beets, of which it is estimated he raised 700 bushels to the acre. On adjoining land not irrigated the crop was almost a total failure. The yield of onions was 400 to 500 bushels per acre, and very large crops of tomatoes were produced. Both onions and tomatoes were also planted on excellent soil near by, which was not irrigated, and their crops were failures. It is reported that the best crop raised by irrigation was celery, and it was as large and finely flavored as any in the market.

In 1895 Mr. A. J. Glidden irrigated 75 acres from his 1,150-foot well northeast of Hitchcock, but the water was not available until May 1, so that the irrigation was not so thorough as desired. The following results were reported: 15 acres of corn yielded 300 bushels; 26 acres of wheat yielded 686 bushels; 3 acres of oats yielded 210 bushels; 5 acres of potatoes yielded 500 bushels. He has a 25-acre reservoir.

Near Conde, Messrs. Buswell and Allen had 7 acres in garden truck in 1894, and 20 acres in 1895, with artesian-water irrigation, and most satisfactory results were obtained.

YANKTON COUNTY.

In the western and southern portions of Yankton County artesian waters are relatively so near the surface that they should be available for irrigation to nearly every farmer. Except in the immediate vicinity of Yankton, comparatively little irrigation has been done so far, and I have heard of but few plans for the development of this resource. The principal irrigation in Yankton has been at the nursery of Mr. G. H. Whiting, where the waters have been used for the irrigation of 30 acres, mainly planted in young trees. The well is 521 feet deep, 3 inches in diameter, and furnishes about 350 gallons per minute. Mr. Whiting states that since the introduction of the artesian water he has obtained an exceedingly satisfactory growth of thoroughly matured trees. In his garden he raised tomatoes, over 300 bushels per acre, that were planted very late and not particularly well cared for. Gooseberries yielded 3,000 quarts per acre. Strawberries and other small fruits were also greatly benefited by the water. In the nursery it was stated that soft maple trees, the seeds of which were planted in June, 1894, had grown to a height of 3 feet in October. Three-year-old apple trees have grown 2½ feet; currant sprouts, 2½ feet; catalpas, 4 feet; and everything else in proportion. On the Lahon fruit farm, near Yankton, artesian irrigation has yielded most excellent results with vegetables and small fruits, of which about 15 acres were irrigated in 1895. Nine acres of potatoes yielded 200 bushels per acre; 4 acres of cabbage yielded 12,000 to 15,000 good heads; 2 acres of onions yielded about 250 bushels per acre, and this on a piece of new land that had been broken only the season before. The well is only 2 inches in diameter, 500 feet deep, and cost $450. Its flow is about 75 gallons per minute. A reservoir has been built at small cost and extensive ditches have been made, and the owners are now prepared to considerably increase the area under irrigation.

ARTESIAN WATERS FOR POWER.

Many of the wells in the artesian basin furnish water under such pressure that they are available as sources of mechanical power. This power has been utilized quite extensively for running flour mills and dynamos for electric lighting, and to a small extent they have also been applied to many minor uses. At Aberdeen the sewage is pumped away by power from a well. The power is one that is very easy to apply and control, and as it in no way interferes with the further use of the water for irrigation or domestic purposes, it may in most cases become an important item of income in well ownership. In Pl. XCVIII

I have indicated the observed pressures in many wells, which will give an idea as to the area in which pressure may be expected and the amount of pressure that has been furnished by wells now in existence.

REMARKS ON THE CONSTRUCTION AND MANAGEMENT OF ARTESIAN WELLS.

Quite a number of wells which were sunk in the Dakotas and found abundant water supplies have since become so damaged as to be of no further use. This has given the impression to many persons that the life of the well is necessarily short, and that the expense of renewing borings and pipings would be so large an item that in the end deep wells could never be economical. This, of course, is not supposed to be the case in every instance, or that all wells would soon give out, but it is thought to introduce a very great element of risk into well ownership. A large amount of special attention was given to this particular point, and I endeavored to ascertain in every case where a well had given out what the causes were, and whether they could have been avoided. In most cases I was unable to secure reliable or definite statements, but enough was learned to convince me that in no case was it inevitable from natural causes that the well should have clogged up or become unserviceable if it had been properly built or suitably managed. The principal cause of failure was found to be clogging up of the well with sand, clay, and other materials from below, that finally cut off the flow or reduced it to so small an amount that the well was no longer used. Another difficulty was the flow of water around the outside of the pipe in such manner that the flow of the well could no longer be controlled. The water would run to waste and in all probability the well would clog itself up.

Well boring is a mechanical art which has been practiced for so many years and by so many ingenious persons that it has reached a high stage of development. As in all industries, there are engaged in the business a large number of incompetent persons whose methods are crude, and, on the other hand, many skillful artisans. I am not prepared to say to what extent the failures of certain wells are due to lack of necessary knowledge of well boring on the part of their constructors or to conditions which at the time could not have been foreseen. Many of the earlier wells were bored by men who were not at that time particularly skillful or learned in their art, but who have since become expert to a high degree; but it is cause for regret that even now wells are occasionally sunk by men with whom the success or failure of a well is largely a matter of chance. It is exceedingly rare that a person having a well bored knows what is going on underground or is an adequate judge of the merits of the well borer. He must trust very largely to the reputation or recommendations which the well borer brings, and he should of course endeavor to secure an experienced and skillful man rather than a cheap contract and a doubtful person. There are, however, a few features of well boring which I can point out in such manner as to aid persons planning to sink wells and at the same time offer to well borers some knowledge that has proved serviceable in other regions where the art of well boring is more highly developed than it appears to have been in the Dakotas.

In the first place, one must bear in mind the enormous forces which the underground waters possess in most of the wells. This force is frequently 500 pounds per square inch at the depth at which the water is struck. Strong casings, properly built machinery, and expert men are absolutely essential to cope with such enormous forces. The mere operation of boring to a depth of from 500 to 1,000 feet or more is a relatively simple matter, and its principle is, I presume, familiar to nearly all persons who are at all interested in wells. A heavy iron rod with a steel bit on its end is dropped a few feet at the rate of 20 to 40 strokes per minute, in such a manner as to break off and churn up the material which is to be penetrated. As the hole is made, pipe for its casing is passed down, more or less closely following the bit, particularly in the case of borings in soft materials, where casing is always necessary to hold up the walls. The pipe is lowered or gently forced down length upon length, each new length being screwed tightly into the coupling of the preceding one, until the water is reached. The churned-up material is either forced out by a stream of water under considerable pressure, which is pumped into the boring, or baled out by a sand bucket, which is a short length of pipe with a large upward-opening valve in its bottom. It often happens that the casing will reach a certain point and go no farther; then a smaller size of pipe must be introduced, and sometimes it has been found necessary to decrease the size of the pipe several times before reaching the water.

With some of the improved machinery now in use this is not so often necessary as formerly, but it is expedient to carry it on to a certain extent for a reason that I will now explain. It is always desirable to have the casing of a well doubled for the greater part of its depth—that is, to have an outer pipe extending nearly to the water and then to have an inner pipe extending to and into the water-bearing bed. The advantages of this arrangement are manifold, but the principal advantage is that when the inner pipe becomes in any way out of order it may be easily withdrawn, repaired, and reinserted or replaced by a new inner pipe. The inner pipe will receive all the wearing by suspended sand, etc., and be subject to the greater part of the corrosion from the waters. These last two factors are not so important as might be imagined, and the life of a good, heavy pipe is an exceedingly long one, particularly if it be galvanized. The principal difficulties occur at the lower end of the pipe, and it is for these mainly that it is desirable to have the inner pipe removable. A most important feature is to have the outer pipe rigidly fixed at its lower end in a hard bed, so that no water may reach the surface along its outer side. In quite a number of cases the waters have begun seeping up around the outer casing until they have finally made a sufficient space to emerge in large volumes, and after that the life of the well usually is soon terminated. There are other cases, too, in which the water would seep up along the outer side of the well casing and find its way, in whole or in part, into some higher horizon, so as to decrease or totally lose its head and volume. A relation of this character is shown in fig. 65.

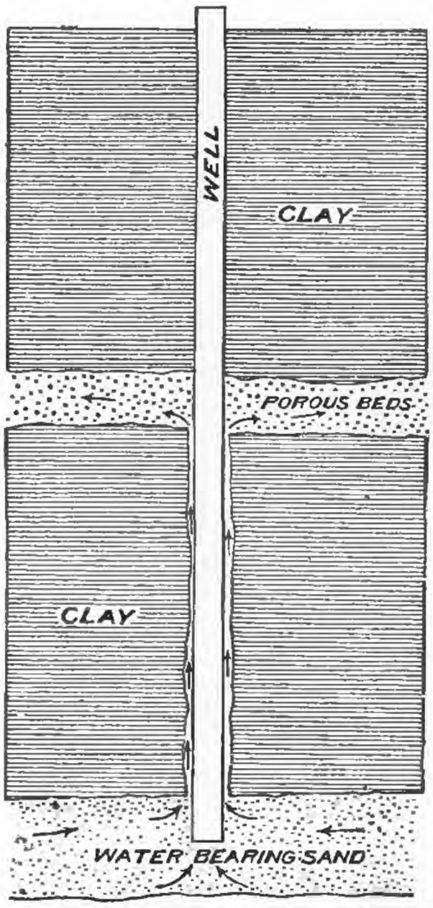


FIG. 65.—Diagram illustrating the escape of waters from a lower into a higher horizon along the outer side of the casing in an artesian well.

It is probably due to this cause in more wells than we suspect that the pressure is so much less than we should expect from the depth and experience of wells in the surrounding district. In many wells, some of which have failed and others of which now, owing to their favorable conditions, are working satisfactorily, the casing supplying the water reaches through the cap rock and has neither an extension into the water-bearing beds nor any anchorage excepting the thin layer of cap rock. This is a dangerous feature, and has caused the clogging or displacement in a number of wells. It is always much safer—and I should advise it in every case—to sink the inner pipe of the well completely through the water-bearing beds to some hard stratum lying next below them, and then sufficiently far into that stratum to hold the pipe rigidly. As it is necessary to have the portion of the pipe that is in the water-bearing beds perforated, to admit the water, it is further desirable to have this portion of the casing of extra heavy piping, to compensate and much more than compensate for the weakness caused by the perforations.

I must acknowledge that there is often great difficulty in managing the completion of the well after a great volume of water has been struck, but I believe that a skillful well borer can in every case properly insert the perforated pipe or strainer and anchor it firmly in bed rock below. The difficulties of working in water having a great pressure are very great, and frequently the well is damaging itself during the delay incidental to its final completion; but there are now so many expedients known to the skillful well borer that he surmounts most of these difficulties with relative ease.

It is very important in constructing and managing a well to prevent the discharge of any large volume of solid matter from the water-bearing beds, for this has been the cause of the clogging up of the greater number of wells which are now unserviceable. The perforated pipe usually obviates the possibility of extensive discharges of solid matter if the perforations be sufficiently small and the pipe be anchored at its bottom in a hard stratum at the base of the water-bearing beds. If this anchorage can not be made, I should advise the introduction of a valve at the open end of the pipe, although it will require no small degree of skill to insert and close a valve of this character. The condition which probably ensues when a well discharges large quantities of solid matter is the development of a large cavity at the lower end of the casing, and eventually the shale roof of this cavity will cave in and seal off the water-bearing bed. In wells that are not so constructed that the solid matter is kept out of the casing by perforated pipe and a secure anchorage in some firm bed lying beneath the water-bearing material, it will be found safer never to let the well have its full flow when it shows any disposition to throw sand or other matter. On the other hand, it is desirable not to shut a well off entirely, because more or less sand is apt to be forced up into the casing and become so set as to completely shut off further flow.

THE WATER RESOURCES OF ILLINOIS.

BY

FRANK LEVERETT.

CONTENTS.

ILLUSTRATIONS.

THE WATER RESOURCES OF ILLINOIS.

By Frank Leverett.

GENERAL STATEMENT.

The paper here presented embraces material gathered chiefly in connection with a detailed study of the glacial drift which the writer began some ten years since. It should therefore be understood that it does not represent a special investigation of the water resources. In the study of glacial deposits natural exposures were found to be so limited that it was necessary to collect well records, and of these about 3,000 were collected in the State of Illinois. They are so distributed as to embrace nearly every county of the State which was encroached upon by the ice sheet. No records have been obtained in the unglaciated counties of southern Illinois aside from a few in the city of Cairo.

The glacial deposits yield such an abundance of good water that over a large part of the State but few wells have gone below these deposits. Where the drift is thin, wells have entered the rock. In northern and western Illinois much prospecting for artesian water has been done.

The "logs" of wells are seldom sufficiently full or reliable to warrant publication, and the writer has had very little opportunity to examine well drillings. From many of the wells, however, information of more or less value has been obtained which throws light upon the character and availability of such water.

No investigation of the water power of the streams has been undertaken further than the collocation of results obtained by others; but the use of streams as sources for city water supply has been investigated, and analyses of waters from this source, as well as from other sources, have been obtained.

A special circular letter pertaining to city water supply was mailed to town officials, or others qualified to give information, in all the towns of the State having a population of 1,000 or more. The generous response to that letter makes it possible to present a somewhat full report upon this subject.

The data on rainfall were obtained from the United States Weather Bureau, and data for the discussion of rainfall for 1895—a year of exceptional drought—were obtained through the assistance of the directors of the State Weather Service in Illinois and adjoining States.

The writer is thus under obligations to many who have supplied information. He is especially indebted to Mr. Daniel W. Mead, C. E., of Rockford, Ill., who, by correspondence as well as by published material, has aided greatly in the preparation of this paper. Mr. Mead has issued several pamphlets dealing with water resources of small areas in Illinois and Wisconsin, and also a pamphlet on the Hydrogeology of the Mississippi River Basin, which presents, largely in tabular form, the material scattered through various State documents of Wisconsin, Minnesota, Iowa, and Illinois, as well as Government publications, and covers a range of topics as wide as those embodied in the present paper, though somewhat different from them.[1]

Thanks are also due to Mr. L. E. Cooley, C. E., of the Chicago Drainage Commission, for assistance in supplying data on the work of that commission in connection with the proposed lake and gulf waterway across Illinois.

Through the kindness of Prof. C. W. Rolfe, of the University of Illinois, the writer was permitted to make a tracing of 50-foot contours from the unpublished map sheets in his office, as explained further on. These contours appear on the base map used in several of the illustrations.

Prof. J. A. Udden, of Rock Island, has made a special examination of the artesian wells in the vicinity of that city, and has submitted a report (published herewith) on the character of the rock formations, based upon his examination of well drillings.

The writer should also acknowledge his indebtedness to Mr. F. H. Newell for numerous valuable aids furnished during the preparation of this paper, and to Prof. T. C. Chamberlin for guidance in field study.

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[1] Hydrogeology of the Upper Mississippi Valley and some of the adjoining territory, by Daniel W. Mead, C. E.: Jour. Assoc. Eng. Soc., vol. 13, No. 7, July, 1894. 68 pages, with 6 maps.

CHAPTER I.

PHYSICAL FEATURES.

ALTITUDE.

Illinois has the distinction of being the lowest of the North Central States. It lies in the midst of the great interior basin, which on the east rises to the Appalachian Mountains and on the west to the Rocky Mountains. The mean elevation of the State is about 600 feet, while that of the bordering States is as follows: Indiana, 700 feet; Michigan, 900 feet; Wisconsin, 1,050 feet; Iowa, 1,100 feet; Missouri, 800 feet.[1]

The State has been covered by a careful barometric survey, conducted by Prof. C. W. Rolfe, of the University of Illinois, a survey which had for its object the preparation of a topographic model of the State for the Columbian Exposition. Professor Rolfe used as datum points the altitudes of railway stations which had been determined by surveyor's level. These are found in nearly every county of the State, at intervals so frequent that there is but little room for error in his maps. He has exercised great care in reducing to a minimum errors arising from barometric fluctuations. From Professor Rolfe's map sheets, which are as yet unpublished, the accompanying map has been prepared, showing the altitude of the greater part of the State by contours with 50-foot interval. In the hilly, driftless tracts in the northwest corner and in the southern end of the State the surface is so uneven that only 100-foot contours are introduced, and for very small areas these are necessarily omitted.[2]

The writer has made an estimate, from Professor Rolfe's map sheets, of the area included between 100-foot contours, the results being as shown in the table on the next page. The highest points are situated in the northern counties, there being four counties (Jo Daviess, Stephenson, Boone, and McHenry) in which points rise above 1,000 feet above tide. In a general way the altitude decreases from north to south. The decrease is, however, far from regular, and a prominent ridge in the southern part of the State rises nearly to the altitude of the northern portion, its crest reaching at one point an altitude of 1,047 feet (Rolfe).

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[1] The average elevation of the United States, by Henry Gannett: Thirteenth Ann. Rept. U. S. Geol. Survey, 1892, p. 289.

[2] In the portion of Indiana embraced in the map, 100-foot contours have been introduced, based principally upon a combination of railway-survey altitudes of towns with aneroid readings taken by the writer and on a general acquaintance with the relief and other features.

A reference to the accompanying map (Pl. CVIII) will serve to make clear the altitudes and slopes of the State.

The highest point in the State (1,257 feet) is Charles Mound, on the Illinois-Wisconsin line, in the northwest county. None of the State is below 300 feet at high-water stages of the Mississippi and Ohio; hence, no account is taken of such portions of their valleys as may fall below 300 feet at low water. It appears from the table below that only 125 square miles, or less than four townships, rise above the 1,000-foot contour, and that only 10,747 square miles, or less than one-fifth of the State, falls below the 500-foot contour. A computation of the average altitude of the State was made by assuming for the area between two consecutive contours an average elevation halfway between these contours. This assumption is not absolutely correct, but, as indicated by Mr. John Murray, in a paper in the Scottish Geographic Magazine,[1] it involves no serious error. The areas between consecutive contours were then multiplied by their assumed average elevations, the several products added together, and the sum divided by the total area of the State. By this method the average elevation of the State is found to be 632 feet, or but little different from the estimate made by Mr. Gannett prior to Mr. Rolfe's survey. It appears from the table that 20,000 square miles, or more than one-third of the State, stands between 600 and 700 feet above tide, or at about the average elevation of the State.

Areas of Illinois between 100-foot contours.

	Square miles.
Above 1,200 feet	1
Between 1,100 and 1,200 feet	6
Between 1,000 and 1,100 feet	118
Between 900 and 1,000 feet	1, 009
Between 800 and 900 feet	3, 981
Between 700 and 800 feet	11, 127
Between 600 and 700 feet	20, 058
Between 500 and 600 feet	9, 603
Between 400 and 500 feet	8, 822
Between 300 and 400 feet	1, 925
Total area of Illinois	56, 650

RELIEF.

The relief of this district is so inconspicuous as to merit but brief attention in a discussion of the water resources. The greater part of the State is so nearly plane that it is difficult to discern the slope

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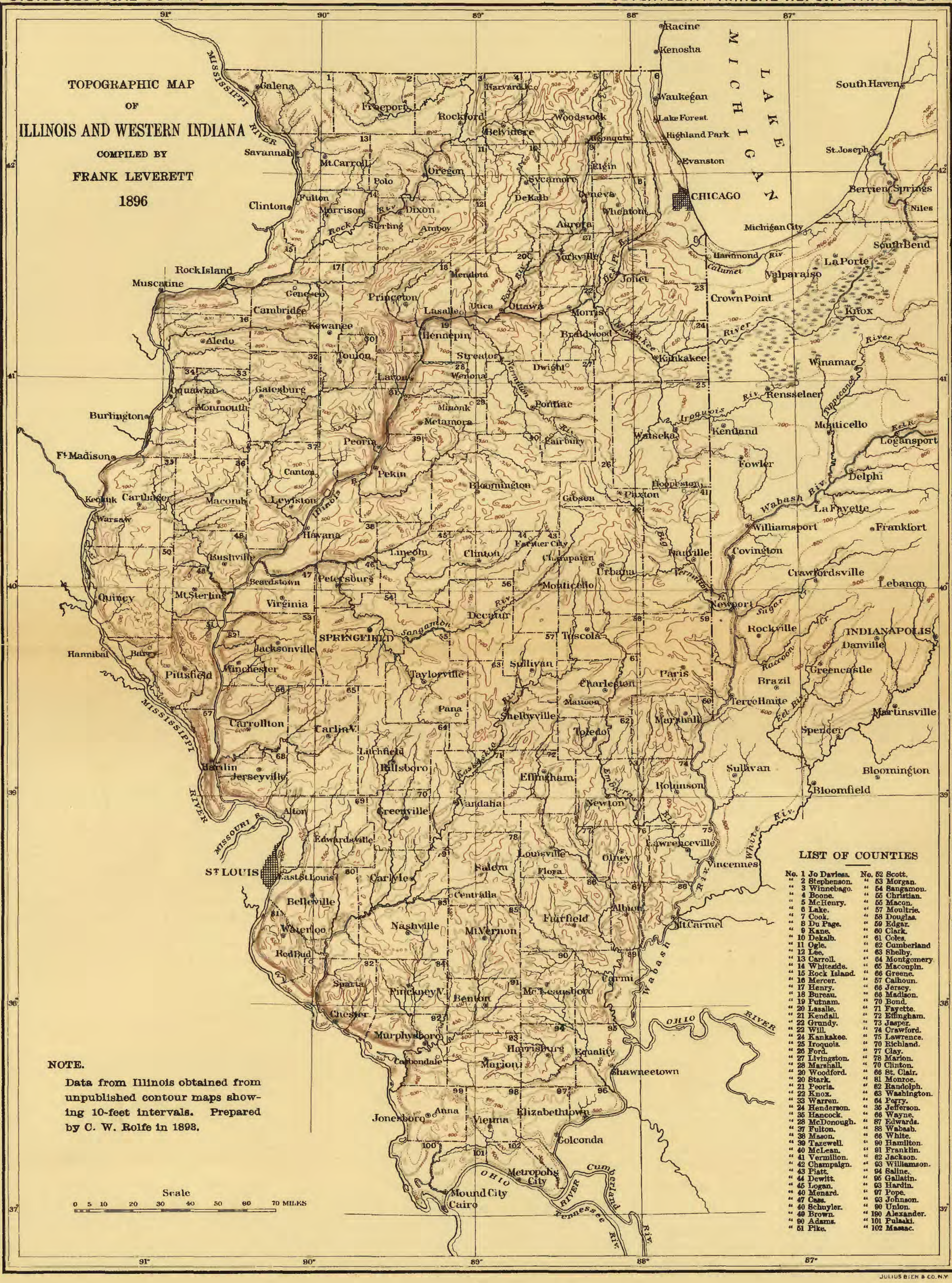
[1] On the height of the land and the depth of the ocean: Scottish Geog. Mag., vol. 4, No. 1, January, 1888.



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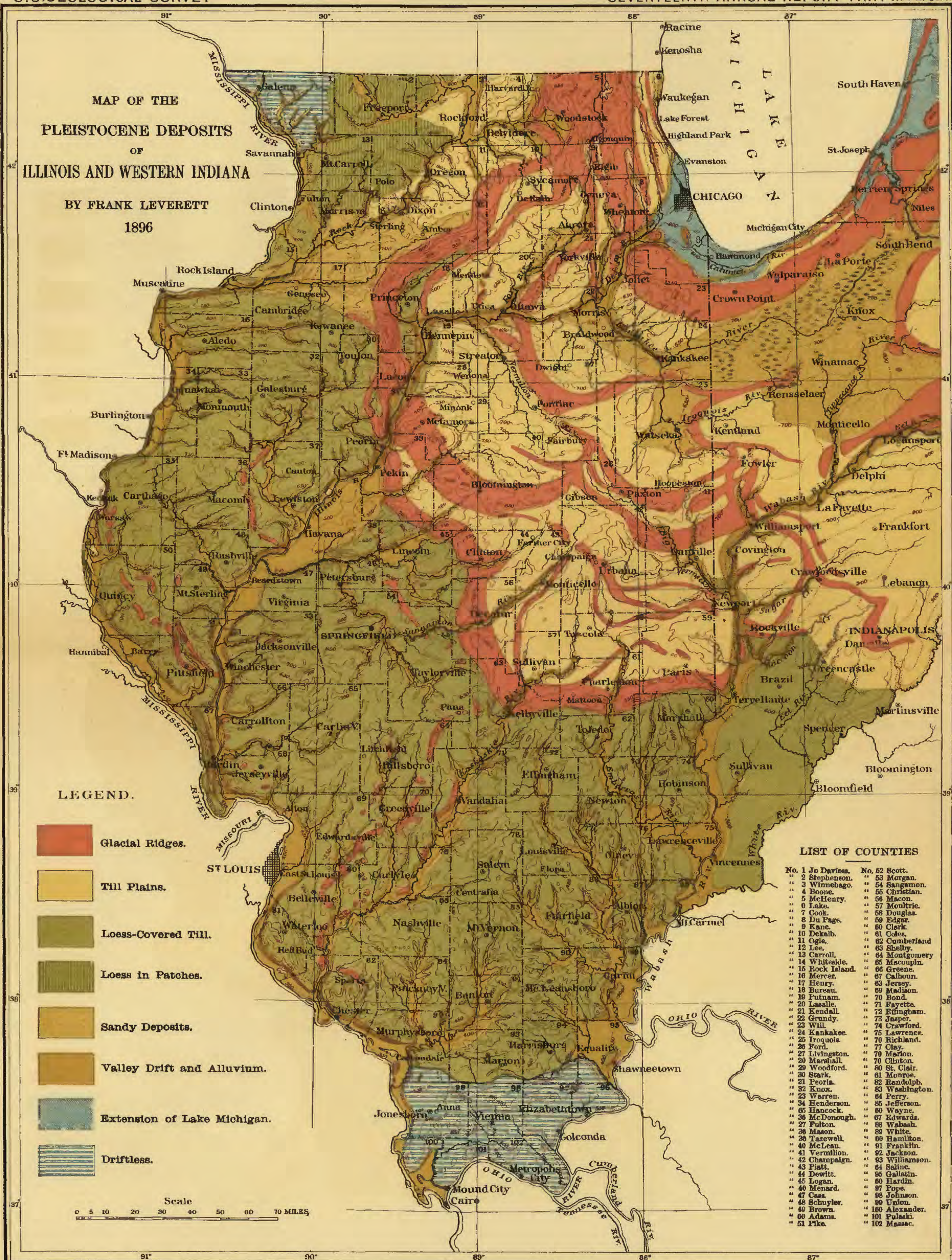

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without instrumental aid. There are, however, a few morainic belts, mentioned on another page, and a few ridges with rock nuclei, which are of sufficient prominence to merit a passing word.

The most prominent ridge is that of the so-called Ozark uplift, in the southern end of the State. This consists of a narrow belt of elevated land, scarcely 10 miles in average width, which crosses southern Illinois in an east-west course from near Shawneetown, on the Ohio, to Grand Tower, on the Mississippi. The crest of the ridge stands mainly between 700 and 800 feet above tide, or about 300 feet above border tracts, but, as previously noted, it rises at one point to a height of 1,047 feet. The points which stand much above 800 feet are, however, rare, and in the form of knobs, as may be seen by reference to the contour map (Pl. CVIII). The importance of this ridge in the discussion of water resources consists not so much in the fact of its being a divide between drainage basins as in its influence upon wells, it being difficult to obtain water along its crest.

In a few places along the eastern border of the Mississippi, from the western terminus of this ridge to the mouth of the Illinois, the Lower Carboniferous limestone rises markedly higher than the Coal Measures plain to the east, its general altitude being about 650 feet, while that of the border portion of the Coal Measures plain seldom exceeds 500 feet. In one place, in southern Jersey County, an altitude of over 800 feet is attained.

In the northwestern counties of the State are the so-called "mounds" of Niagara limestone, which rise abruptly 75 to 300 feet above bordering portions of the upland. In the aggregate these mounds cover but a few square miles. They are the remnants of formations which were once continuous over this region, as has been indicated by Professor Worthen.[1]

In the southeastern portion of the State, on the borders of the Wabash, there are a few low ridges and mounds of Coal Measures strata which rise above the general level of the bordering plains to heights seldom exceeding 100 feet. These are of very limited extent, covering in the aggregate but a few townships.

Aside from these instances the rock surface very rarely rises above the general level of the drift cover. It is probable that beneath the drift cover of the State there are forms similar to those of the district bordering the Wabash, and perhaps in the northern portions there are mounds as conspicuous as those of Jo Daviess County which have been covered by the heavier accumulations of drift which occur there. Such reliefs can be made out only by careful study of well borings and a full knowledge of the thickness of the drift.

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[1] Geology of Illinois, Vol. I, 1866, p. 4.

EFFECT OF THE DRIFT UPON TOPOGRAPHY AND DRAINAGE.

The discussion of the drift features will help to an understanding of peculiarities of drainage as well as of the topography, for the drift has a topography of its own, which to a great degree determines the boundaries of drainage basins.

The southern limit of the glacial drift in Illinois is at the northern border of the prominent ridge above noted, which crosses the southern end of the State. Eastward the glacial boundary soon enters Indiana, but northwestward it remains within the limits of the State as far as St. Louis, and leaves the valley nearly free from till as far north as Quincy. Thin deposits of drift cover the greater part of the limestone ridges which appear along the east bluff of that portion of the Mississippi. From Quincy northward nearly to Savanna heavy deposits occur, which have in two cases (at the Des Moines and at the Rock Island rapids) been sufficient to displace the pre-glacial stream and compel it to excavate a new channel—in the Des Moines rapids for a distance of about 12 miles, and in the Rock Island rapids (with the continuation to Muscatine in a narrow valley) a distance of 40 miles. Above Savanna is the driftless area of the Upper Mississippi, which in its Illinois portion covers much of Jo Daviess County and portions of Stephenson and Carroll counties.

In southern Illinois, for about 75 miles north from the extreme limits of glaciation, or to about the latitude of St. Louis, Mo., the drift is so thin that it has not greatly changed the principal pre-glacial lines, its usual thickness being scarcely 30 feet; but north from that latitude the streams rarely for any great distance follow pre-glacial lines. The notable exceptions are the Mississippi, which follows pre-glacial drainage lines throughout much of its course, and the lower Illinois, which from the bend near Hennepin to its mouth, a distance of over 200 miles, is mainly in a pre-glacial valley.

Of the drift-covered district north from the latitude of St. Louis, a large portion has such an amount of drift as to completely conceal the pre-glacial features. This includes almost the entire northeastern third of the State. West and south of this tract of very heavy drift there are many places where the pre-glacial divides can still be discovered, and in a rude way the drainage conforms to that of pre-glacial times; the valleys tend to follow pre-glacial lines, though they seldom coincide with them; the water partings tend to follow pre-glacial divides, but are not strictly coincident with them.

The complete concealment of pre-glacial features is restricted mainly to the limits of the ice invasion which terminated at the Shelbyville moraine, the position of which is indicated on the accompanying glacial map (Pl. CIX). It will be observed that this moraine crosses the Kaskaskia at Shelbyville, the Sangamon a few miles west of Decatur, and the Illinois at Peoria. From Shelbyville it passes eastward into Indiana;

from Peoria it passes northward, with an occasional slight curve to the east, into Wisconsin. The drift to the west and south from this moraine is markedly older than the moraine, and is called the older drift. This moraine and the surface portion of the drift in the district between it and Lake Michigan are called the newer drift.

The drainage systems have reached a much more advanced stage in the older drift than in the newer. The difference in stage of development is so marked, as represented in the topographical model of the State, prepared by Professor Rolfe, that it is said to have occasioned much comment from visitors at the World's Columbian Exposition, where the model was exhibited. This feature is apparent also on the topographic map here presented (Pl. CVIII). It can not be urged that greater advantages for the development of drainage lines are to be found in the older drift, for, so far as altitude and slope are concerned, the newer drift has the advantage, it being generally more elevated and more diversified in slope than the older drift. The differences in the structure are not great, the drift throughout both sections being composed mainly of bowlder clay. The bowlder clay of the newer drift is now more easily eroded than that of the older, but the hardness of the older drift may have been acquired since drainage lines were developed in it.

The average thickness of drift for the entire glaciated portion of the State is about 75 feet. The thickness of the drift in the district outside of the Shelbyville moraine is less than half as great as that of the district between the moraine and Lake Michigan. It is estimated that the newer drift of Illinois, although confined to less than half the drift-covered portion of the State, is as great in amount as the older drift. The usual thickness of the older drift, aside from filled valleys, is but 20 to 50 feet, while the thickness where both the older and newer drift are present is usually 100 to 150 feet. This great contrast in thickness is to be seen at the border of the Shelbyville moraine, and is shown by the relief of the moraine above districts west and south of it, as well as by the borings, which reveal corresponding distance to rock. On the contour map (Pl. CVIII) it will be observed that two of the 50-foot contours are usually required to indicate the relief of the moraine above the district south and west of it.

In the portion of the State covered by the newer drift there is a succession of morainic ridges formed by the ice sheet during its retreat from the Shelbyville moraine. These ridges are separated by drift plains or basins from a mile or two up to 30 or 40 miles in width. These plains usually show a gradual rise on their landward (west and south) borders, while on the iceward borders (toward the Lake Michigan basin) they are found to rise abruptly to a moraine. The streams which now drain this region naturally chose the axes of these basins for their main channels, while the slopes carry the tributaries. It is the long slopes on the west and south and the short slopes on the opposite side which have caused the tributaries of the streams to be mainly from the west and south.

In the older drift there are very few morainic ridges, and these have seldom controlled drainage. As a rule, the drainage lines of that part of the State either conform to pre-glacial lines or follow belts where through some incident in drift filling the surface was left slightly lower than the general level. In the newer drift the high ground which determines the position of the main water partings is ordinarily a morainic ridge, but in the older drift it is usually the line of a pre-glacial divide. A brief review of the drainage features will make this apparent.

In southern Illinois the present division of the waters between tributaries of the Wabash and tributaries of the Mississippi corresponds in a rude way with that of pre-glacial times. Many of the small branches disregard pre-glacial lines, but the main streams entering both the Wabash and the Mississippi depart but little from pre-glacial lines of similar-sized streams.

In southwestern Illinois the present water parting between streams flowing northeast to the Sangamon and those flowing southwest to the Illinois conforms to a pre-glacial divide; but the small streams which lead from this divide to the Sangamon and the Illinois are thought to have taken their present courses through some deficiency in the drift-filling, for several of them are cutting new channels in rock in portions of their courses.

In the district lying between the lower course of the Sangamon and the Shelbyville moraine there is a pre-glacial basin filled so heavily with drift that the streams are entirely independent of pre-glacial drainage.

In western Illinois the present water parting between the Illinois and Mississippi apparently follows in the main the pre-glacial divide. In Pike County, however, Bay Creek, a tributary of the Mississippi, was evidently tributary to the Illinois in pre-glacial time, and was forced by the presence of the ice sheet near its mouth to cross an old watershed in its westward course to the Mississippi.

In northwestern Illinois changes of much consequence have occurred. The pre-glacial Rock River appears to have passed southward from Rockford to the Illinois Valley at the bend near Hennepin. The old valley is traceable as a trough, partially filled with drift, to the vicinity of Rochelle, in southeastern Ogle County, where it passes beneath the Shelbyville moraine and its further course is completely concealed. The present stream enters a new valley near the mouth of the Kishwaukee and crosses an old upland through Ogle and northwestern Lee counties, where it enters a lowland known as the Green River Basin. It crosses this lowland tract, and near its mouth enters the uplands again to join the Mississippi in its course across the Rock Island rapids. The stream is therefore not only in a new course, but in a course which shows remarkably little regard for the pre-glacial topography. The lowland referred to was formerly connected with the lower Illinois, but, like the southward course of Rock River, it became completely filled by the Shelbyville moraine, and the drainage was forced westward into the Mississippi either at the time that moraine was formed or at the time of an earlier ice invasion. Green River now furnishes the line of discharge for the main part of this lowland, but drains it very inadequately.

The district to the northwest of Rock River has apparently suffered slight changes of drainage. The main western tributary of Rock River, the Pecatonica, is in its pre-glacial course, but a western branch of that stream (Yellow Creek), entering at Freeport, has been beheaded, the head-water portion having been turned into the Mississippi through Apple River by a deposit of drift in the middle course of the old stream north of Stockton. The drainage of northern Carroll County has also been changed by drift deposits in the old valleys. A good illustration is found in Carroll Creek, which is in a new course at the rapids near Mount Carroll, while its head waters follow an old valley which apparently entered the Mississippi several miles farther south than the present mouth of the stream.

Considering the newer drift, the Shelbyville moraine, although as prominent as any of the moraines in Illinois, does not to any marked degree constitute a water parting. It is crossed by small as well as by large streams which have found their sources in the somewhat elevated plain on its north and east borders.

A prominent water parting is found in a moraine, or rather system of moraines, which north from Peoria is closely associated with the Shelbyville moraine, but which southeast from that city lies much farther north—the system on or near which Bloomington, Gibson City, Paxton, and Hoopston are situated, and which is termed the Bloomington system. From this morainic system the Sangamon and several of its northeastern tributaries lead southwest, the Big Vermilion leads southeast, the south branches of the Iroquois lead north, the Illinois-Vermilion leads northwest, and the Mackinaw leads west.

Between this morainic system and the Shelbyville moraine there is in eastern Illinois a less prominent morainic system, well developed near Champaign, and known as the Champaign moraine, which forms the head of the Kaskaskia and the Embarras rivers. The plain between this moraine and the stronger moraines to the north is drained at the west by the Sangamon and at the east by tributaries of the Big Vermilion and by Little Vermilion River.

The Illinois-Vermilion River drains an extensive plain lying between the Bloomington morainic system and a later morainic system (the Marseilles), following closely the southwest border of the later system.

The Mackinaw River follows for a short distance the inner (northeast) border of the Bloomington morainic system and then turns southwest across it and continues across the Shelbyville moraine into the Illinois. The other streams mentioned, as a rule, take courses directly away from the moraines, though Big Vermilion flows for much of its course in a narrow trough between two members of the Bloomington morainic system, and Little Vermilion follows throughout much of its course the north border of the Champaign moraine. The Iroquois drains an extensive plain or drift basin between the Bloomington and the Marseilles moraines—a basin noted for the flowing wells which it yields—and also a small basin in western Indiana, inclosed by a moraine of the Erie-Saginaw series, through which it passes just west of the State line. (See Pl. CIX.)

North of the Illinois is Fox River, in its lower course draining a plain lying west of the Marseilles moraine, and having tributaries mainly on its west side, because it follows closely the border of the Marseilles moraine. The head-water portion of Fox River for a distance of 75 miles lies in the midst of morainic ridges.

On the inner border of the Marseilles moraine, around the head of the Illinois, is a plain or basin drained in its northern portion by Au Sable Creek and in its southern portion by Mazon Creek. The slope of this basin throws the drainage eastward to the head of the Illinois. Upon entering that stream the water returns westward, passing through the moraine and out of the basin at Marseilles.

A narrow drift ridge (the Minooka moraine) runs south into this basin as far as the head of the Illinois. To the east of this ridge is a narrow plain drained by the Dupage, whose eastern border is the Valparaiso moraine.

From the head of the Illinois a plain some 25 miles in width extends eastward far into Indiana, constituting the main part of the drainage basin of the Kankakee. On its north is the Valparaiso moraine (named from Valparaiso, Ind., which is situated upon it), while on its east and south are moraines belonging to the Erie-Saginaw series. (See Third Ann. Rept. U. S. Geol. Survey, Pl. XXXI.)

Between the Valparaiso moraine and Lake Michigan, Calumet River is found at the east and the Des Plaines and Chicago rivers at the north. Calumet and Chicago rivers discharge into Lake Michigan, but the Des Plaines turns southwest through the Valparaiso moraine, following a former outlet of Lake Michigan to the Illinois known as the "Chicago Outlet." Throughout most of its course before entering the Chicago Outlet the Des Plaines flows in a narrow drift basin having the Valparaiso moraine on its western and a smaller moraine on its eastern border.

The well borings, and also to some extent the valleys of the present Fox, Des Plaines, and Kankakee rivers, throw some light upon the *probable position of the pre-glacial divide west of Lake Michigan.* They show that the Niagara limestone rises westward from the border of Lake Michigan to an altitude 50 to 100 feet or more above the present lake level, along a line leading southward across northeastern

Illinois. This elevated portion of the limestone is crossed by Fox River below Elgin, by Des Plaines River between Lemont and Joliet, and by the Kankakee a short distance east of the State line. It seems highly probable that this constituted a pre-glacial water parting, and that the head-water portions of Fox, Des Plaines, and Kankakee rivers were in pre-glacial times tributary to the Lake Michigan basin. This ridge is the only probable water parting in the entire region covered by the newer drift of Illinois which the writer was able to recognize.

THE CHICAGO OUTLET OF LAKE MICHIGAN.

The southwestward or "Chicago Outlet" of Lake Michigan, as pointed out some years since by Col. James H. Wilson and William Gooding, C. E.,[1] by Dr. H. M. Bannister,[2] and by Dr. Edmund Andrews,[3] entered the present Des Plaines Valley immediately west of Chicago and passed thence down to the Illinois. The effect of this outlet upon the size of both the Des Plaines and the Illinois is very marked. The upper portion of the Des Plaines down to the point where the ancient stream entered the valley is a small channel, 20 to 30 feet in depth and scarcely one-eighth mile in width, cut into the soft deposits of glacial drift. Upon entering the outlet the stream finds a valley more than a mile in average width, and cut to a depth of 50 to 100 feet or more, the depth varying with the altitude of bordering uplands. The excavation is mainly in drift, but for a few miles above Joliet it extends 25 feet or more into the rock.

The Illinois flows for a few miles in a low drift basin lying west of the Marseilles moraine, in which the ancient stream was expanded into a lake which built beaches instead of eroding a channel; but from the Marseilles moraine onward a large valley is cut, having an average depth of more than 100 feet and a width of about 1½ miles throughout the new course above Hennepin and nearly 3 miles in the old part of the valley below that town.

To appreciate how small a part of this excavation on the Illinois is due to the present drainage lines, one has only to turn to such tributaries as Fox and Vermilion rivers and compare the small channels cut by them with the large valley of the upper Illinois, for they are all cut to about equal proportions in the drift and in rock formations of similar kind. Fox River, which includes about one-fourth of the present drainage of the upper Illinois, has in its lower 75 miles a channel with about one-eighth the width and one-half the average depth of the upper Illinois, and is even better favored than the Illinois in its rate of descent. Instead of 25 per cent of the amount of excavation displayed by the Illinois, this stream has accomplished scarcely one-fourth that amount. It seems probable that at least three-fourths of the excavation of the

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[1] Rept. U. S. Army Engineers, 1868, p. 442.

[2] Geology of Illinois, vol. 3, 1868, pp. 240-242.

[3] Trans. Chicago Acad. Sci., vol. 2, 1870, pp. 1-23.

upper Illinois, and even more of the portion of the Des Plaines occupied by the lake outlet, was accomplished by that ancient stream. In the lower Illinois, where the ancient stream worked entirely upon the loose materials of the drift, the excavation was larger in amount, and the valley presents a remarkably low gradient—so low that the present stream is silting up instead of eroding its bed. The fall of the stream in its lower 225 miles is but 30 feet. Whether this very low gradient is entirely due to the lake outlet or has been brought about in part through a warping of the valley has not been determined. It is certain, however, that the valley was opened throughout its entire course to a far greater amount than the present streams could have accomplished. No attempt will be made to discuss here the causes for the change in the outlet of Lake Michigan, since it involves great complications both of glacial retreat and of crust warping, neither of which is as yet well understood.

DRAINAGE BASINS.

The Mississippi receives probably three-fourths of the drainage of Illinois, mainly through the Rock, Illinois, and Kaskaskia rivers. The Wabash and Ohio receive nearly all of the remaining fourth, there being but a very small part of the State tributary to Lake Michigan.

ILLINOIS RIVER.

Of the streams which traverse Illinois, the Illinois is by far the largest, its drainage area being fully half as great as the area of the State and lying mainly within the State boundaries. The drainage area of the Illinois is estimated by Greenleaf, in his report for the Tenth Census, to be about 29,000 square miles. The estimate made by the Chicago Drainage Commission reduces it to 27,914 square miles. This area is distributed in three States, of which the proportion in each State is estimated by Greenleaf as follows: Illinois, 24,726 square miles; Wisconsin, 1,080 square miles; Indiana, 3,207 square miles. The drainage areas of the chief tributaries, given in order from source to mouth, also estimated by Greenleaf, are as follows:

Drainage areas of the chief tributaries of the Illinois River.

Stream.	Square miles.	Stream.	Square miles.
Des Plaines River	[a]1,758	Mackinaw River	1,182
Kankakee River	[b]5,302	Crooked Creek	1,286
Fox River	2,697	Sangamon River	5,592
Vermilion River	1,413	Macoupin Creek	1,000
Spoon River	1,905		

[a] The Chicago Drainage Commission estimates this area as 1,392 square miles.

[b] Estimated by the Chicago Drainage Commission as about 5,146 square miles.

The drainage area or watershed of the Illinois extends in a broad band, averaging 100 miles in width, in a northeast-southwest direction directly across the center of the State. From the northeastern extremity of this band there are two projections—one north into Wisconsin, including the Fox and Des Plaines river basins; the other east into Indiana, including the Kankakee and its main tributary, the Iroquois. The name Illinois is applied to the river from the junction of the Kankakee and Des Plaines. The western side of the watershed is 20 to 40 miles in width, while the eastern side is 60 to 80 miles.

The Illinois River is a stream showing marked contrasts in the rate of fall. From the junction of the Des Plaines and Kankakee westward for 50 miles, being in a new course, its bed is usually on the rock, and it has an average fall of about 1 foot per mile; but in the remainder of its course to the Mississippi, a distance of about 225 miles, it is in a pre-glacial channel and has, as previously stated, a very slight fall. This portion of the Illinois is discussed more in detail further on.

Des Plaines River.—The Des Plaines is a stream with moderate descent from its source to a point near the line of Cook and Will counties, a few miles southwest of Chicago, where it begins a rapid descent. It makes a fall of about 70 feet in 8 miles, when just below Joliet it reaches a pool known as Joliet Lake, which continues nearly to its mouth.

Kankakee River.—The Kankakee, for about 90 miles from its source, flows through a great marsh and descends scarcely 100 feet; but in the lower 50 miles of its course it descends about 135 feet over a rocky bed. Notwithstanding this rapid descent, the lower course of the river is not subject to disastrous floods, the rise above the ordinary stage being seldom more than 5 or 6 feet. The flow is equalized to some extent by the marsh in its upper section and by sand deposits which border the lower course and receive much of the surplus water from the tributaries.

Fox River.—This river has a length of about 130 miles, and drains a tract 15 to 30 miles in width. In the upper half of its course it winds about sluggishly through sloughs, marshes, and lakes, in the midst of a great system of moraines; in the lower half of its course it is a rapid stream. From the vicinity of Elgin to its mouth its bed is usually in the rock. The fall in its passage through Kane and Kendall counties is about 3 feet per mile, but in Lasalle County it increases to about 5 feet per mile, making a descent of nearly 125 feet in the lower 25 miles of its course. In its upper course tributaries are small and the flow is somewhat regular, but in the lower course several tributaries are received from a district in which slope and structure favor rapid run-off, and these produce the high stages of the river, sometimes reaching 10 or 15 feet above the normal.

Illinois-Vermilion River.—Vermilion River has a length of about 75 miles and drains a till plain perhaps 20 miles in width. This plain descends with the stream northwestward, so that for 50 miles scarcely any valley is formed, though there is a descent of nearly 100 feet. In the lower 25 miles the stream corrades rapidly, making a descent of about 150 feet and cutting its valley mainly in rock. This stream is subject to great variations in water height. It has not the marshy gathering ground of the tributaries just considered, and the drift formations in its basin are mainly of compact till which yields but little water in seasons of drought.

Spoon River.—Spoon River and Crooked Creek, the main western tributaries of the Illinois, have valleys cut mainly in drift, but exposing rock at many points along the base of the bluffs. They probably follow approximately lines of pre-glacial drainage throughout much of their courses, but are not strictly coincident with such lines. The rate of fall is more regular than in the tributaries just described. Spoon River in the lower 80 miles of its course, south from Stark County, descends from 2 to 3 feet per mile. Crooked Creek is nearly as regular in the lower 50 miles of its course, though more rapid. In the head-water portions of both streams the descent is more rapid than in the lower courses, thus reversing the habit of the upper tributaries of the Illinois. Both streams are subject to great variations in water stages because of rapid run-off. The rapidity of run-off is due to rapid fall and the generally well-drained surface. In seasons of drought springs along the valleys and main tributaries afford a considerable supply of the water.

Mackinaw River.—This river drains a somewhat elevated plain in northern McLean County, standing 300 to 350 feet above the Illinois. In its middle course in Tazewell County it breaks through a moraine, and there only has it excavated a valley of much depth. In the lower 20 miles it winds about in the Illinois Valley in a shallow channel, making a descent of about 75 feet. This stream is one of the most variable in the State in quantity of water, being subject to great floods in wet seasons and becoming nearly dry in seasons of drought. The variability is due to several causes—rapid fall, compact drift beds, and absence of head-water marshes being the principal ones.

Sangamon River.—Extensive plains in central Illinois are somewhat inadequately drained by the Sangamon River, whose tributaries do not ramify as thoroughly as is necessary for good drainage, and the area given as its catchment basin represents not that actually drained, but that which may, by extensive ditching, be drained into it.

The length of the river is about 180 miles. It rises in the morainic ridges of McLean County, at an altitude of about 850 feet above tide, or over 400 feet above its mouth (the mouth being 429 feet). In the first 10 miles it makes a descent of 120 feet, thus leaving 300 feet of fall for the remaining 170 miles of its course. The fall is far from regular, there being sections often several miles in length in which it is slight, between which are sections with more rapid fall. Thus in its course through Sangamon County, a distance of 36 miles, it falls only 38 feet, while in crossing Menard County, immediately below, it falls 67 feet in a distance of 30 miles, and in crossing Macon County, just above Sangamon, it falls 50 feet in about 30 miles. In the lower 23 miles, where it crosses the Illinois bottoms, its fall is only 16 feet.

This river in seasons of drought reaches a very low stage, becoming almost dry. The till plain which it drains yields very little water to the streams except immediately after rains have fallen. Freshets now seldom last more than a few days, and are said to be much briefer than before the district was brought under cultivation.

Macoupin Creek.—Macoupin Creek, Apple Creek, and other small tributaries of the lower Illinois show a rapid descent, their head waters being nearly 300 feet above the Illinois. They traverse a district in which drainage lines ramify through nearly every section. The drift being largely a compact till, rainfall is absorbed slowly. These streams therefore carry off a large amount of water, but in dry seasons they almost cease flowing.

ROCK RIVER.

Rock River, which drains much of northwestern Illinois, has a length of nearly 300 miles, its general course being southwest from southern Wisconsin across northwestern Illinois. Nearly one-half its length is in Wisconsin. The drainage basin has an area of about 11,000 square miles, of which slightly more than one-half is situated in Wisconsin. The greatest width is near the State line, where it is about 80 miles. The Wisconsin portion averages 40 or 50 miles, but in Illinois the basin suddenly narrows to 40 miles, and then to 25 miles. It is mainly a prairie region, though bodies of timber of considerable size are found within its limits. Above Janesville, Wis., where it leaves the Kettle moraine of the Green Bay lobe, the basin is characterized by extensive swamps and numerous small lakes which feed it in dry seasons. The Illinois portion is mainly undulating and well drained, though extensive swamps occur along Green River, an eastern tributary. From the Kettle moraine southward to the mouth of the Kishwaukee the river occupies an old valley, but above and below these points it follows new lines because of the filling of the old valley with glacial drift. The river derives its name from the rock ledges which it crosses in the new portions of its course, not only in the upper section but in the lower, as at Sterling, Ill., where there are rapids with a fall of about 15 feet in a distance of 2 miles.

The altitude of the stream at its source is about 875 feet and at its mouth 536 feet. The most rapid section, aside from short rapids, such as those at Sterling, is in southern Wisconsin, from the mouth of the Catfish to the mouth of the Pecatonica, where, for a distance of 30 miles, the average slope is nearly 2 feet per mile. This slight increase of slope is attributable to the greater accumulation of drift deposits in the northern end of the section than in the southern, the northern being in the vicinity of the Kettle moraine, which poured its gravel into the old valley to the south and caused a gradually decreasing amount of filling in passing from the moraine southward.

Rock River has three principal tributaries entering within the State of Illinois—the Pecatonica, the Kishwaukee, and the Green. The drainage area of the Pecatonica lies mainly within the State of Wisconsin. This stream is in a region which is well drained, and in consequence is fed but little during seasons of drought by swamps or lakes. The Kishwaukee River heads in an elevated morainic district and falls rapidly throughout its course, but as it is bordered by extensive deposits of gravel connected with marshes its flow is somewhat regular. Green River, also, is in a region bordered by swamps and gravelly deposits, which keep its flow somewhat regular.

The small tributaries in the Illinois portion of the drainage basin are, in the main, streams with rapid fall, and are usually free from swamps or deposits which will hold water. As a consequence they often become dry throughout portions of the year.

In Wisconsin the small tributaries are usually bordered by swamps, and contribute a somewhat regular flow to the river.

TRIBUTARIES OF THE MISSISSIPPI IN WESTERN ILLINOIS.

Both above and below the mouth of Rock River several small rivers enter the Mississippi, the principal streams above being Fever, Apple, and Plum rivers, and those below, Edwards and Henderson rivers and Bear Creek.

The first-mentioned group lie mainly in the driftless region, and have a very rapid but generally well-graduated descent. The rapid fall promotes a speedy escape of surface water; but, bordered as they are by limestone ledges from which springs issue, the stream beds seldom become dry.

The tributaries south of the mouth of Rock River drain till plains which stand only 200 to 300 feet above the Mississippi. Edwards River, draining parts of Henry and Mercer counties, with a length of nearly 60 miles, has a regular descent and an average fall of about 5 feet per mile. Its tributaries are small and it is seldom subject to freshets. Springs from the drift prevent the stream from becoming as low in seasons of drought as many streams of this size in central Illinois. Henderson River, draining much of northern Henderson, northern Warren, and part of Knox counties, is a more widely branching stream and subject to greater variations in volume than Edwards, though draining about the same amount of territory (450 to 500 square miles). With a length of nearly 50 miles, it makes a somewhat regular descent of 7 to 8 feet per mile to within 15 miles of its mouth, where it enters the Mississippi bottoms and thence falls but little. Bear Creek, draining western Hancock and northern Adams counties, is a widely branching stream, subject to high freshets and very low stages. At times it almost ceases flowing, though it drains an area of about 500 square miles.

KASKASKIA RIVER.

The Kaskaskia, or Okaw, is the principal river traversing southern Illinois. With a length of 180 miles, it drains nearly 6,000 square miles. Its source is in a moraine near Champaign, at an altitude of about 730 feet above tide. Its descent is gradual, even in the head-water portions, there being a fall of only 110 feet in the first 50 miles of its course. Its most rapid section is in its course through Moultrie County, where it makes a descent of 55 feet in about 18 miles, or 3 feet per mile. In places there are pools several miles in length, the most conspicuous of these being found in St. Clair County, where in a distance of over 20 miles the fall is scarcely 10 feet.

The stream is subject to great variations in volume, as it drains a region in which the substrata are of compact clay, which promotes a rapid run-off and furnishes but little water in seasons of drought. A rise of 20 feet in its lower course is not rare, and its flood plain has been built nearly to that height above the stream bed.

BIG MUDDY RIVER.

The only remaining important tributary of the Mississippi is the Big Muddy, a stream draining about 2,400 square miles in the low district lying north of the Ozark Ridge. It is a stream of comparatively low rate of fall, yet it is subject to freshets with a rise of 25 feet or more. Greenleaf reports the rise at Murphysboro to be 30 feet. In dry seasons it almost ceases flowing. Its great fluctuations, like those of the Kaskaskia, are largely due to the compact clays which underlie the region and prevent absorption of the rainfall.

TRIBUTARIES OF THE WABASH.

There are several tributaries of the Wabash, viz, Little Wabash, Bon Pas, and Embarras rivers, which, like the Big Muddy and Kaskaskia, have low rates of descent and yet are subject to great variations in volume, largely because of the compact clay of the region which they drain. The head-water portion of the Embarras, however, north from Cumberland County, drains a district with looser substrata. The Big and Little Vermilion rivers also drain districts in which the substrata are pervious, and in consequence they present a more uniform stream than the tributaries farther south. Big Vermilion, however, because of a very rapid descent in its lower course and the widely branching head waters, is subject to great freshets.

CHAPTER II.

THE RAINFALL.

In its rainfall the State of Illinois is, on the whole, well adapted for profitable agriculture. It is rare that any part of the State is subjected to a complete loss of any of its crops, either by drowning or by drought. The rainfall throughout the entire State, however, is subject to marked variations from year to year.

Records of rainfall are obtainable at a few points in Illinois and on its borders for a period of forty-five years, and at many points for fifteen to twenty years or more. From these records Mr. Harrington, formerly of the United States Weather Bureau, has estimated the average precipitation to be about 38 inches.[1]

The precipitation frequently amounts to several inches more than the normal, and there have been two years in which it exceeded 50 inches; it also frequently falls several inches below the normal, and occasionally is less than 30 inches. There is, therefore, in very wet years nearly twice as much rainfall in the State as in years of extreme drought. If single stations are considered, the wet years frequently show more than twice the precipitation of very dry years. While rainfall records are valuable in showing the average conditions, they are seldom sufficiently complete to indicate the probable effect upon crop production. Even records of daily rainfall are imperfect, since they seldom show the rate of downpour or the condition of the soil at the time of the rainfall, and these are factors of great importance in determining the efficiency of the rainfall in the production of crops. An inch of rain coming gently, when the soil is in condition to absorb it, may have a greater efficiency than several inches of downpour on a soil already saturated.

The tables below set forth as fully as may be in compact form the main results of rainfall records in Illinois and border districts. The first table shows the annual and seasonal averages for Illinois and neighboring States, compiled from Mr. Harrington's results in the bulletin on rainfall and snow. From this table it appears that Illinois is among the most favored of this group of States in the fall of rain during the portion of the year when it is needed for crops, 80 per cent of its comparatively large rainfall being in the spring, summer, and autumn months. As the ground is usually frozen throughout the greater part of the State in the winter months, precipitation, unless in the form of snow, is of little value. A blanket of snow often proves

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[1] Rainfall and snow of the United States, compiled to 1891, by Mark W. Harrington: U. S. Dept. of Agriculture, Weather Bureau Bull. C, 1894, p. 56.

of great service in protecting winter wheat and grass lands, and in this respect Illinois is about as well favored as any of these States, and usually better favored than neighboring States to the west.

Table of annual and seasonal rainfall averages for Illinois and neighboring States.

State.	Area.	Spring.	Summer.	Autumn.	Winter.	Annual.	Cubic miles.
	Miles.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
Illinois	56,650	10.2	11.2	9.0	7.7	38.1	34.0
Missouri	69,415	10.0	12.4	9.1	6.5	38.0	41.2
Iowa	56,025	8.3	12.4	8.1	4.1	32.9	28.8
Minnesota	83,365	6.5	10.8	5.8	3.1	26.2	34.4
Wisconsin	56,040	7.8	11.6	7.8	5.2	32.5	28.7
Michigan	58,915	7.9	9.7	9.2	7.0	33.8	31.3
Indiana	36,350	11.0	11.7	9.7	10.3	42.7	24.2
Ohio	41,060	10.0	11.9	9.0	9.1	40.0	25.7
Kentucky	40,400	12.4	12.5	9.7	11.8	46.4	29.3

The following table of yearly variations in rainfall has been compiled from Mr. Harrington's rainfall bulletin for the years 1851–1891, from the report of the Chief of the United States Weather Bureau for 1892 and 1893, and from the official bulletin of the Illinois State Weather Service for 1894 and 1895.[1] With the stations in Illinois have been included those on the immediate border in adjoining States. These are of value, for in the earlier years there were but few stations at which rainfall was recorded.

Table showing yearly variations in rainfall of Illinois.

Year.	Number of stations.	Average.	Range.
		Inches.	*Inches.*
1851	5	54.1	45.4–74.5
1852	5	47.8	38.4–59.4
1853	4	38.9	30.9–45.2
1854	6	34.1	23.6–46.3
1855	6	41.7	29.1–50.5
1856	9	32.7	23.3–43.9
1857	9	34.1	27.5–39.8
1858	13	51.1	45.2–68.8
1859	11	37.3	26.5–61.3
1860	8	33.9	25.2–56.2
1861	13	39.0	30.0–68.6
1862	13	46.7	34.9–70.4

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[1] Weather and Crops, by C. E. Linney, director Illinois State Weather Service, Chicago.

Table showing yearly variations in rainfall of Illinois—Continued.

Year.	Number of stations.	Average.	Range.
		Inches.	*Inches.*
1863	11	33.5	25.6–50.4
1864	15	31.4	24.0–38.3
1865	16	40.0	24.5–51.8
1866	17	36.9	30.2–45.3
1867	19	30.2	22.4–40.2
1868	19	38.0	25.9–45.6
1869	20	41.8	30.4–51.5
1870	21	30.0	20.3–41.3
1871	18	32.3	22.6–40.8
1872	19	31.8	24.8–39.5
1873	18	38.3	19.7–54.5
1874	20	33.2	23.8–47.5
1875	20	40.5	26.9–59.5
1876	22	45.3	34.5–62.6
1877	20	41.9	33.3–54.9
1878	20	37.9	31.2–45.6
1879	20	32.0	21.5–52.3
1880	24	39.5	30.6–53.2
1881	22	41.8	32.7–56.4
1882	24	43.8	33.0–70.8
1883	27	44.1	33.7–61.5
1884	25	42.1	32.8–66.6
1885	27	39.5	32.1–50.1
1886	33	34.0	18.9–50.6
1887	33	32.2	16.1–38.3
1888	33	37.3	26.0–62.9
1889	34	34.7	24.4–42.8
1890	34	38.3	23.5–49.8
1891	32	33.0	25.9–45.1
1892	49	41.4	31.1–63.3
1893	53	34.1	20.3–48.8
1894	75	29.3	18.2–40.4
1895	97	31.9	19.7–46.4

The average rainfall shown in the above table is slightly lower than that given by the United States Weather Bureau, being 37.85 inches instead of 38.10. This is due to the exceptionally low rainfall of 1893–1895, which was not included in the estimate by Mr. Harrington. The average of the above table to the close of 1891 is 38.21 inches.

Of the forty-five years' record, it will be observed that twenty-two years are above and twenty-three years below the average (37.85 inches) rainfall. The period of most remarkable precipitation is that of 1875–1885, inclusive. But one year was below the normal, and the average for the period of eleven years is 40.76 inches, or nearly 3 inches above the normal. The succeeding ten years have been marked by equally great deficiency. Only one year has been much above the normal, while seven have been much below, and the average is but 34.62 inches, or more than 3 inches below the normal. This period of drought is generally considered the most severe in its effects since the settlement of the State. It has resulted the past two years (1894–95) in a failure of wells and drying up of brooks and springs to an extent not known before. It has not, however, been remarkably disastrous to crops, since the little rainfall which occurred was adjusted to their needs. Just before the eleven-year period of great rainfall there was a period of twelve years (1863–1874, inclusive) marked by a deficiency in rainfall. Only two years were much above the normal, while seven years were much below it, and three were near the normal. The average precipitation for the twelve years is 35 inches, or nearly 3 inches below the normal. In the twelve years which preceded (1851–1862, inclusive) the few records given show an average of nearly 41 inches. Of these there are five years much above the normal, three years near the normal, and four years much below the normal. It is therefore not so strikingly a wet period as that of 1875–1885, when nearly every year was above the normal. The high average is due to the remarkably great precipitation in the wet years. Reviewing the above observations, the records suggest that there may be an alternation of wet and dry periods with a length of eleven to twelve years. They cover too brief a space, however, to warrant generalizations of much value.

In this connection it may be remarked that the reports of the United States Weather Bureau and the records of the State Weather Service show an apparent periodicity in several other of the North Central States. In Wisconsin, from 1863 to 1874 the average rainfall was but 30.22 inches, and only one year (1870) showed a precipitation greater than the normal. In 1875 to 1885 the average rainfall was 37.66 inches, and in none of these years was the rainfall so low as the normal (32.5 inches). In 1886 to 1895 the average rainfall was only 30.43 inches, and in only two years of the ten was the rainfall above the normal. The wet and dry periods stand out less clearly in Iowa than in Wisconsin and Illinois, but this is largely due to the enlargement of territory over which observations are made in the later periods. Down to 1875 the Iowa observations were mainly in the eastern part of the State, where rainfall is heaviest, while from 1875 onward the observations extend over the less humid western portion. From 1851 to 1862 the rainfall in eastern Iowa was slightly above 40 inches, while from 1863 to 1874 it was about 35 inches. The rainfall of the entire State from 1875 to 1885 was about 36 inches, while from 1886 to 1895 it was only 28.97 inches. The normal for the entire State in twenty years (from

1875 to 1895) is 32.58 inches. In the period from 1875 to 1885 the rainfall in but one year (1879) was markedly below the normal, while in the period from 1885 to 1894 it was but one year (1892) markedly above the normal, though slightly above in one other year (1888).

An examination of the records in Missouri affords little evidence of the periodic variation. Of the States to the north and west of Iowa, Nebraska and South Dakota present, in the last twenty years, a distribution of precipitation above and below normal similar to that shown in the three States just considered, but North Dakota and Minnesota do not show such a distribution, at least not in so marked a degree. In Nebraska the observations prior to 1875 are mainly in the eastern part of the State, and accordingly do not indicate so low a rainfall as would be expected were the more arid western portion included. This eastern portion, however, shows an average rainfall of only about 24 inches from 1868 to 1874, while the records for 1875 to 1885, from a much wider area, show an average rainfall of 28 inches. This was followed by a period of less rainfall, the average for the years 1886 to 1895 being but 22.34 inches. The normal rainfall for Nebraska is about 25 inches. The rainfall was not markedly below this amount in any year between 1875 and 1885, while in the period from 1886 to 1895 it rose above the normal in but one year (1891). In South Dakota the records prior to 1875 are mainly from the southeast portion, which is the most humid, and yet the records from 1869 to 1874 show an average yearly rainfall of but 18.55 inches. From 1875 to 1885 the average was about 25 inches, and throughout much of this period the entire State was fairly well represented by stations. In the period from 1886 to 1895 the average yearly rainfall has been barely 20 inches. In but one year (1892) did it rise to the average rainfall of the preceding decade.

These observations are certainly suggestive of periodic variations in rainfall, covering as they do an area of several States. It will be a matter of importance to note, as time goes on, whether the teaching of the weather records sustains periodicity. If definite alternate wet and dry periods occur, the agriculture can be adjusted to the conditions and shortage of crops of certain kinds be foreseen.

Since making the above estimates from the rainfall records, I have found the following allusion to eleven-year cycles in Davis's Meteorology:

> It is true that slight fluctuations of rainfall and temperature in nearly eleven years, corresponding to the sun-spot cycle, have been made out at certain stations for a moderate number of periods; but the fluctuations have not yet been shown to be general, uniform, and persistent. A longer variation is indicated over Europe and in certain other countries in a period of thirty-six or thirty-seven years, as shown by Brückner's review of all available records of dry and wet years, high and low stages in rivers, abundant and scanty crops, etc.; but at least another century will be needed fully to confirm this result and to extend it over the world.[1]

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[1] Elementary Meteorology, by William Morris Davis, 1894, p. 346.

It is deficiency rather than excess of rainfall which injures the crops, even in Illinois, the most humid of the States in the group just discussed. A deficiency of rainfall has never been so serious in Illinois as to cause complete failure of any crop over a great part of the State, such as the less humid States to the west and northwest have experienced. Its greatest danger lies in a deficiency between June and September, there being many years when the corn and other crops which ripen in autumn are shortened by drought at that season. It is often the case that heavy rains and low temperature from April to June keep the ground cold and damp. Then a reversal of conditions suddenly occurs and the ground becomes baked by the hot, dry atmosphere and blazing sun. Much of central and southern Illinois, where the flat surface prevents ready escape, or the nearly impervious subsoil prevents ready absorption of the rainfall, is subjected to this baking process, and the fertility of the soil is greatly checked thereby.

In the following table the range in rainfall is shown at each of the stations in Illinois and on its borders where observations have been kept for periods of several years:

Table showing range in rainfall at the principal stations.

Station.	Years of record.	Lowest.		Highest.		Range.
		Inches.	Year.	Inches.	Year.	
Anna	1876–86	37.6	1881	55.3	1876	17.7
Augusta	1857–80	25.5	1879	54.0	1862	28.5
Aurora	1866–95	30.3	1866	47.9	1892	17.6
Athens	1851–58	25.2	1856	47.3	1858	22.1
Cairo	1872–95	26.6	1872	61.5	1882	34.9
Centralia	1880–91	35.5	1881	59.8	1883	24.3
Chicago	1867–95	22.4	1867	45.8	1883	23.4
Collinsville	1883–91	31.1	1891	44.8	1888	13.7
Dubois	1864–73	26.0	1871	52.7	1873	36.7
Elmira	1866–82	24.4	1867	42.3	1869	17.9
Geneseo	1874–87	23.0	1886	42.6	1877	19.0
Golconda[a]	1879–95	33.7	1887	70.8	1882	37.1
Grand Tower	1886–90	28.9	1887	48.5	1890	19.6
Griggsville	1882–95	25.9	1891	50.5	1894	24.6
Galesburg	1862–71	23.1	1870	42.9	1862	19.8
Greenville	1883–95	33.5	1891	66.6	1894	33.1
Havana	1871–77	30.4	1874	45.6	1876	15.2
Hennepin	1871–78	26.0	1874	37.3	1876	11.3

[a] By including earlier observations a rainfall of but 30.4 inches is found at Golconda in 1868 and 30.7 inches in 1869, thus increasing the range to 40.4 inches.

Table showing range in rainfall at the principal stations—Continued.

Station.	Years of record.	Lowest.		Highest.		Range.
		Inches.	Year.	Inches.	Year.	
Irishtown	1886–91	31.6	1891	42.8	1888	11.2
Louisville	1870–80	33.7	1872	62.6	1876	28.9
McLeansboro	1882–95	30.0	1887	56.4	1883	26.4
Manchester	1856–72	26.1	1871	49.4	1858	23.3
Mattoon	1880–95	24.2	1895	52.9	1872	28.7
Mount Carmel	1886–95	35.7	1887	59.3	1894	24.6
Marengo	1851–91	24.0	1864	56.9	1851	32.9
Mount Sterling	1870–80	21.7	1879	50.7	1876	29.0
Oswego	1880–95	27.4	1888	43.1	1894	15.7
Ottawa	1856–95	23.6	1887	55.7	1862	32.1
Palestine	1883–95	35.3	1887	54.1	1883	18.8
Pana	1883–93	35.2	1884	63.3	1892	28.1
Philo	1886–95	28.9	1891	41.4	1895	12.5
Peoria	1856–95	23.6	1870	53.4	1862	29.8
Pontiac	1886–91	16.1	1888	30.3	1891	14.2
Rockford	1874–95	23.8	1874	47.5	1884	23.7
Rock Island	1867–91	19.7	1873	43.8	1869	24.1
Sandwich	1860–91	25.9	1868	70.4	1862	44.5
Springfield	1880–95	25.2	1887	58.2	1883	33.0
Sycamore	1882–95	25.3	1889	51.0	1883	25.7
Winnebago	1858–95	26.5	1859	45.2	1858	19.7
Watseka	1886–90	29.4	1888	37.0	1890	7.6
Wyanet	1866–75	27.9	1867	51.5	1869	23.6
New Harmony, Ind	1854–83	23.3	1856	48.9	1880	25.6
Dubuque, Iowa	1861–95	18.3	1894	55.4	1881	37.1
Muscatine, Iowa	1851–94	23.6	1854	74.5	1851	50.9
Fort Madison, Iowa	1856–95	22.2	1879	52.3	1852	30.1
Keokuk, Iowa	1872–95	22.5	1879	51.5	1876	29.0
Louisiana, Mo	1878–94	21.5	1879	41.1	1884	19.6
St. Louis, Mo	1851–95	22.6	1871	68.8	1858	46.2
Beloit, Wis	1861–88	20.3	1870	46.4	1881	26.1

From the above table it appears that 6 of the stations show a range of over 3 feet in amount of yearly rainfall, while 27 of the 49 stations show over 2 feet variation, and the few stations in which there are variations of less than 1 foot are among those which have kept records for only a few years. Of the 24 stations which have kept records for more than fifteen years none show a variation of less than 15 inches. An examination of the dates of highest and lowest rainfall at the different stations shows that they do not correspond in any marked degree to the dates of high and low rainfall for the entire State. At the majority of stations the extremes in precipitation mark simply local excess or deficiency, and they serve to indicate the great influence of such local conditions. As already remarked, so much depends upon several poorly known conditions, such as the rate at which the rain descends, the power of the winds to absorb moisture, and the condition of the soil at the time of a rainfall, that even tables of daily rainfall may convey wrong or inadequate conceptions as to excess or deficiency of precipitation. Much more is this the case where monthly, seasonal, or annual averages are consulted.

It may be said that in general in Illinois a rainfall below 25 inches results unfavorably to crops, but it not rarely occurs that average crops have been grown where there has been for a single year a rainfall slightly below that amount, and where, even for a succession of years, it has been but little above. If, therefore, it is found, as in the above table, that at nearly half the stations the rainfall has been as low as 24 inches, it should not be inferred that the deficiency resulted in serious damage to crops. Often a year with 30 inches or more of rainfall at a given station has a more prolonged and serious drought in the growing season than one with but 24 inches. Judging from the experience in more arid districts to the west of Illinois, a rainfall of but 20 inches in a year, if well adjusted to the needs of crops, may be sufficient to made a region productive.

It may not be safe, however, to assume that a humid region can be reduced suddenly to a rainfall so low as that which will supply an arid region with a sufficient amount of moisture for the growth of cereals. Investigations by Prof. Milton Whitney, of the United States Department of Agriculture, have shown that where the subsoil is dry, as in the arid region of western United States, the rainfall is less liable to be drawn down into the earth to a depth beyond the use of plants than it is where a moist subsoil occurs. Concerning this matter Professor Whitney remarks:

> There is one factor which has a very important bearing upon the conditions in the humid as compared with those in the arid regions. In the humid regions of the Eastern States the soil is continuously moist from the surface down to a depth at which it is completely saturated and from which water is constantly flowing out into wells, streams, and rivers. The water descends through the soil both by virtue of its own weight and by capillary force. According to capillary laws the water is pulled downward when the subsoil contains less water than the soil. Gravity and capillary force are both more effective in moving water through a moist subsoil than a dry one; hence there is danger in the East of the water being pulled down below the reach of plants in time of drought, while in the West, where the subsoil at the depth of a few feet is continuously dry, this could not happen.[1]

In the three following tables are set forth the details of precipitation

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[1] Yearbook of U. S. Dept. of Agriculture, 1894, p. 156.

at a few points representative of the State of Illinois, extracted from the reports of the Weather Bureau:

Table of rainfall, by months, in percentages.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.
Cairo, Ill., July, 1871, to Dec., 1891	9.4	9.4	8.9	8.7	8.7	10.3
St. Louis, Mo., Nov., 1870, to Dec., 1891	6.3	8.3	7.9	8.7	10.5	13.4
Springfield, Ill., July, 1879, to Dec., 1891	5.9	9.3	6.7	7.8	12.9	13.2
Keokuk, Iowa, Aug., 1871, to Dec., 1891	4.8	4.8	6.0	8.3	11.4	14.0
Peoria, Ill., *a* 18 years	4.7	5.9	6.8	8.8	10.1	12.7
Chicago, Ill., Nov., 1870, to Dec., 1891	6.2	6.5	7.0	8.8	10.2	10.2
Rockford, Ill., *a* 15 years	6.9	6.1	6.9	8.3	9.0	12.0
Davenport, Iowa, Apr., 1872, to Dec., 1891	5.3	4.7	6.5	8.0	12.4	12.4
Dubuque, Iowa, Aug., 1873, to Dec., 1891	6.4	5.5	6.7	6.1	9.8	12.0
Averages	6.2	6.7	7.0	8.2	10.5	12.2
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cairo, Ill., July, 1871, to Dec., 1891	8.2	6.6	5.7	6.4	10.0	7.7
St. Louis, Mo., Nov., 1870, to Dec., 1891	8.9	6.8	8.4	6.8	7.9	6.1
Springfield, Ill., July, 1879, to Dec., 1891	6.4	6.4	8.5	8.5	8.0	6.4
Keokuk, Iowa, Aug., 1871, to Dec., 1891	12.6	8.8	10.0	8.8	5.7	5.4
Peoria, Ill., *a* 18 years	10.2	8.3	10.2	9.2	6.4	6.3
Chicago, Ill., Nov., 1870, to Dec., 1891	10.4	10.0	7.9	9.0	7.6	6.2
Rockford, Ill., *a* 15 years	10.73	9.6	8.0	9.7	6.2	6.0
Davenport, Iowa, Apr., 1872, to Dec., 1891	10.6	11.2	9.4	8.9	5.9	4.7
Dubuque, Iowa, Aug., 1873, to Dec., 1891	11.7	9.8	12.3	8.7	6.1	4.9
Averages	9.9	8.6	9.0	8.5	7.1	6.0

a Taken from charts by Capt. H. H. C. Dunwoody, Signal Office, Washington, 1889.

Table of greatest consecutive number of days with rain.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Cairo, Ill., *a* July, 1871, to Dec., 1891	7	11	7	7	8	13	7	6	8	6	7	10
St. Louis, Mo., Nov., 1870, to Dec., 1891	8	11	6	7	7	9	7	8	5	7	7	10
Springfield, Ill., July, 1879, to Dec., 1891	8	10	7	8	9	7	7	9	5	7	6	7

a In September and October, 1891, 13 consecutive days of rainfall.

Table of greatest consecutive number of days with rain—Continued.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Keokuk, Iowa, *a* Aug., 1871, to Dec., 1891	7	8	7	6	6	7	7	8	6	7	6	8
Chicago, Ill., *b* Nov., 1870, to Dec., 1891	7	12	12	9	10	10	7	10	9	8	12	8
Davenport, Iowa, Apr., 1872, to Dec., 1891	7	8	8	6	9	11	7	9	7	8	6	8
Dubuque, Iowa, Aug., 1873, to Dec., 1891	9	8	6	6	9	11	6	9	7	7	5	6

a In July and August, 1882, 11 consecutive days of rainfall.
b In July and August, 1880, 17 consecutive days of rainfall.

Table of greatest consecutive number of days without rain.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Cairo, Ill., *a* July, 1871, to Dec., 1891	10	9	15	12	13	12	16	16	27	15	12	13
St. Louis, Mo., *b* Nov., 1870, to Dec., 1891	12	12	9	13	11	23	19	23	15	15	14	18
Springfield, Ill., July, 1879, to Dec., 1891	7	8	13	16	10	10	18	15	14	14	10	11
Keokuk, Iowa, *c* Aug., 1871, to Dec., 1891	14	15	13	14	15	16	15	19	16	15	22	16
Chicago, Ill., Nov., 1870, to Dec., 1891	12	21	10	10	16	11	13	16	14	15	16	15
Davenport, Iowa, *d* April, 1872, to Dec., 1891	10	16	12	10	12	9	14	15	15	15	13	14
Dubuque, Iowa, *e* Aug., 1873, to Dec., 1891	14	21	12	16	10	12	11	14	15	14	14	15

a The longest period without rain is 28 days, in September and October, 1891.
b The longest period without rain is 28 days, in June and July, 1871.
c The longest period without rain is 26 days, in October and November, 1879.
d The longest period without rain is 24 days. in August and September, 1888.
e The longest period without rain is 26 days, in September and October. 1888.

In the table of rainfall by months it will be noted that there is a decrease in amount of precipitation in the winter months in passing from south to north. This difference in winter precipitation gives the southern end of the State more rainfall than the central and northern portions, there being very little difference in the amount of rainfall throughout the State in the spring, summer, and autumn months. The month of June has generally, throughout the State, a larger amount of rainfall than any other month. The precipitation in July and August, though averaging nearly as much as that of the spring and autumn months, is subject to great variations, there being in some years but a fraction of an inch in one or the other of these months, while in other years each month may have several inches of rainfall. The rain in these months is also very liable to be in the form of local showers, by which small areas may become well watered though in the midst of a drought-stricken district. The tables indicate that precipitation is greater during these months in the northern than in the central and southern parts of the State, and it is quite generally true that the northern portion suffers far less from the summer drought than the central and southern portions. This should perhaps be attributed only in part to the difference in precipitation, for the northern portion has a soil better adapted to withstand drought than has much of the remainder of the State, as is shown further on. Evaporation would also naturally be less rapid in the northern than in the southern part because of the higher latitude.

The tables of consecutive days with and without rain serve to indicate the comparative length of rainy and dry periods. It will be seen that the greatest length of rainy periods for each month is, with very few exceptions, markedly less than that of dry periods. These tables are nearly in accord with those showing the percentage of days with or without rainfall which appear in the reports of the United States Weather Bureau. At the stations included in the tables given above, the following is the mean percentage of days in which rain fell during the periods covered by the tables: Cairo, 38.5 per cent; St. Louis, 38.4 per cent; Springfield, 42.7 per cent; Keokuk, 35.4 per cent; Chicago, 44 per cent; Davenport, 40.8 per cent; Dubuque, 37.1 per cent.

As the recent great drought is several times referred to in the course of the discussion, a few observations concerning it are made at this point. The drought extended from June, 1894, to the early part of November, 1895, a period involving the whole of one growing season and the greater part of another. It is also the chief part of the season in both years during which evaporation is great. In the seventeen months of this period the rainfall was about 39 inches, or only 1 inch above the normal annual rainfall. The uniform prevalence of the drought is well shown by the records of the State Weather Service stations, which indicate that in 1894 no one of the 56 stations in the State had a precipitation so great as the average normal precipitation, and in 1895 only 7 stations out of 97 in Illinois and on its borders had a precipitation above the normal. The rainfall from April 1 to November 30, 1894, the growing season, was 7.66 inches less than the normal, and in the same part of 1895 it was 5.54 inches less than the normal. In 1895 a heavy rainfall in July (5.36 inches) greatly helped the corn and other crops which mature in the fall, and contrasted strongly with the same month in 1894, when there was but 1.45 inches of rainfall, an amount about half the normal for that month. The general effect of this drought has been no more disastrous to crops in Illinois than that of previous droughts, as, for example, the one which prevailed in 1870, 1871, and 1872; but the recent drought has, as already indicated, produced a greater lowering of the ground water and reduction of the supply in springs and shallow wells than any heretofore experienced.

In a discussion of water resources the minor contributions of moisture in the form of dew merit consideration. This is especially true in a region like Illinois, where in seasons of drought the heavy dews often partially offset the deficiency of rainfall. Very few observations of value have as yet been made upon this subject, and these are mainly based upon the erroneous supposition that dew is contributed almost wholly by the atmosphere. It is probable that the amounts contributed by the several sources—air, earth, and vegetation—vary greatly at different places and at different seasons in a given place, and it may be no easy task to make the discriminations. In damp regions the ground doubtless contributes a large part of the dew, and is probably a chief source of moisture for frost. It has been estimated that the dew precipitated in Great Britain would measure 1½ inches in depth, but as measurements are difficult the estimate may be only a rude approximation.[1] In some seasons of drought the effect of dews upon the crops of Illinois apparently equals a rainfall of 1 inch or more.

The benefit of dew is recognized by observant farmers, and a striking contrast in the effect of droughts which are accompanied by dew and those not so accompanied is appreciated and commented upon. In Illinois, however, there are other conditions accompanying drought which are far more influential than presence or absence of dew. A prevailing cloudiness, or freedom from hot, dry winds from the southwest, often carries a crop through a season of drought more prolonged than could be endured under a clear sky, even though accompanied by dew, to say nothing of one in which there is a clear sky with a scorching southwest blast.

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[1] Elementary Meteorology, by W. M. Davis, p. 156.

CHAPTER III.

THE RUN-OFF.

QUALIFYING CONDITIONS.

The run-off for any given area is dependent upon several conditions, the more important of which are rainfall, slope, perfection of drainage lines, geological structure, vegetation, and temperature. For any given locality the slope of surface, stream bed, perfection of drainage, and geological structure may be assumed to be constant, while the other factors are variable. But if we take into consideration a large area like the State of Illinois, all factors are variable.

The slope of stream beds, as indicated above, ranges from the very low rate of descent of the lower Illinois, with a fall of but 30 feet in 225 miles, to a descent, as in the lower portion of the Des Plaines, Kankakee, Fox, and Vermilion rivers, of several feet per mile. Throughout much of the State, however, the main streams depart but little from a fall of 2 feet per mile, while the Mississippi, lower Illinois, and lower Wabash fall much less than 1 foot per mile. The small streams seldom fall at a more rapid rate than 5 to 10 feet per mile, except in the small head-water tributaries. On the whole, therefore, the slope of stream beds is low, and run-off, so far as influenced by them, is moderate.

With very few exceptions the slope of the surface is low. Aside from the rock mounds and ridges above noted and a few sharp drift knolls and prominent morainic ridges, the slopes are seldom greater than 20 feet per mile, and it is estimated that over fully half the State they are less than 10 feet per mile. The slopes in the older drift region (that lies outside the Shelbyville moraine, Pl. CIX) are, as a rule, less rapid than in the newer drift, because of the rare occurrence there of moraines or other drift ridges to give the surface relief. This lack of relief is, however, compensated for in the older drift by greater maturity of drainage systems.

Throughout much of the newer drift area there is a very imperfect system of drainage, with areas often several square miles in extent in which no channel has yet been opened; while in the older drift and in the driftless portions of the State a comparatively perfect system of drainage has been developed. In much of the older drift, drainage lines are so well arranged that there remain only occasional tracts of a few acres along water partings where no surface outlet occurs; such poorly drained tracts seldom reach a square mile in extent. The conditions for escape of water are therefore less favored by original slope in the older than in the newer drift, but are better favored by perfection of drainage lines.

The geological structure presents important variations. Although the single term "drift" is made to cover the surface deposits of much of the State, it does not follow that there is uniformity. The drift deposits vary as greatly in their capacity to absorb the rainfall as do the several rock formations which appear within the State. Were their thickness sufficient to compare with the pervious rock formations, the gravel and sand of the drift would have no equal among indurated rocks in capacity to absorb moisture. On the other hand, the compact clay, such as covers much of southern Illinois, can scarcely be equaled by any of the rock strata of Illinois in its power to withstand the penetration of water. The drift deposits are so variable in structure from place to place, and also in vertical section, that it is difficult to indicate precisely the extent of any particular deposit. On the whole, the surface gravel and sand are of importance only in the northern part of the State. They include much of the Kankakee drainage basin and of the portion of Illinois lying north of the west-flowing part of the Illinois River. The gravel deposits are especially abundant in McHenry, Kane, and Dupage counties, both on uplands and along valleys. In counties farther west they are confined mainly to valleys or lowlands. The effect of these deposits is to give a regular run-off, for they often absorb sufficient rainfall to furnish in seasons of drought a larger amount of water than is supplied by the rainfall of such seasons.

The absorption by the earth, or ground storage, is probably a much more potent factor than any yet mentioned. Throughout the heated term the ground water is usually lowered to such a degree as to give the earth great capacity for absorbing the rain. It thus happens that the heaviest rainfalls of July and August seldom greatly increase the discharge of streams, while those of May or June, even though less in amount, may, because of the saturated condition of the soil and subsoil, produce disastrous floods. A large amount of water is usually to be found in the earth at levels above that of adjacent stream beds. The surface of this ground water corresponds more nearly with the surface of the ground than with the horizon of adjacent stream beds. In wet seasons, in humid districts such as Illinois, it is raised quite to the surface, while in dry seasons it is lowered a few feet by evaporation, by plant absorption, and by escape to streams. It seldom, however, becomes so low as to reach the horizon of stream beds, and therefore contributes water to the streams in dry as well as in wet periods. It thus happens that for a period of several months the run-off from a drainage basin may exceed its rainfall.

Surface storage is another important modifier. Where there are lakes or basins in which the water is collected and fed slowly to the streams, as in the Kankakee and Green River basins, the discharge of streams is equalized and made somewhat uniform throughout the year, even though the rainfall varies greatly in different seasons of the year. Whether or not surface storage greatly diminishes the amount of run-off depends upon the amount of evaporation or absorption, and varies with different drainage basins.

Vegetation may either increase or retard the escape of water, and does not greatly affect the amount discharged. Its retarding effect may be seen by comparing the rapid rise of streams after a heavy rain in districts where there are cultivated fields with the less rapid rise where the streams are bordered by forests or by dense grasses. On the other hand, it is often the case that under moderate rainfall cultivated fields absorb water more rapidly than meadows.[1]

The temperature also modifies the amount of run-off at any given place, there being more rapid disposal of rainfall by evaporation in the heated seasons than in the colder portions of the year.

The above considerations may be embodied in the following statement: The run-off from any district indicates the excess of precipitation over the evaporation and absorption which take place in that district. As evaporation and absorption, as well as precipitation, vary in the different seasons of the year, and to some degree from year to year, the volume of a stream is usually subject to considerable fluctuation, and it becomes not an easy matter to estimate the normal run-off.

USUAL REGIMEN OF ILLINOIS STREAMS.

In Illinois the volume of the streams has a series of seasonal variations, there being three periods when the volume is great, two periods when it is low, and one period when it is moderate.

The order of events is about as follows: During the winter, when the ground is frozen and precipitation is comparatively light, the streams are low. In early spring the thawing of the ground and the greater precipitation lead to a spring freshet, when the streams are often bankfull or even overflowing. This freshet usually occurs in March or early in April. For a few weeks after this freshet the streams are at a moderate stage, slightly above the normal. This is followed by the "June rise," occasioned by the great rainfall which occurs in that month, when streams often reach as high a stage as in the spring freshet. After the June rise the streams usually drop to a low stage and remain low through the heated term, evaporation and absorption being so great as to dispose of nearly all the rainfall. In the autumn, about the autumnal equinox or a little later, heavy rains occur, which cause the streams to become swollen for a few days, or even weeks, but which seldom cause them to overflow their banks. In some years these seasonal variations are slight, and the streams show but little change in volume, but such years are exceptional. The rainfall is seldom sufficient to cause freshets to last for more than a few days. The moderate and low stages are estimated to generally cover ten months of the year, and occasionally eleven months.

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[1] For data concerning the effect of different methods of cultivation on the amount of absorption and depth of soil moisture, see discussion by Prof. Milton Whitney, Yearbook of U. S. Department of Agriculture, 1894, pp. 159-162.

During a period of years when the rainfall is above the normal the streams reach a very low stage only for a small part of the year, whereas in periods of low rainfall a low stage is maintained for a large part of the year. Such has been the case in the dry period of 1894 and 1895, there being but a few weeks of the seventeen months covered by the drought in which the rivers rose above the ordinary low flow, and much of the time they were far below it. The run-off for these years amounts to but a small fraction of the ordinary discharge. In streams visited by the writer in southeastern Iowa, it is estimated to be not more than one-tenth. Thus in Skunk River, which is estimated by the proprietors of mills on its lower course to have an ordinary low-water flow of about 600 cubic feet per second, the low-water stage for much of the seventeen months of drought was but 50 to 100 cubic feet per second.

STREAM MEASUREMENTS.

But few measurements or reliable computations have been made on Illinois streams, but such as have been made cover some of the largest streams of the State or its borders. On the Mississippi at Grafton (just below the mouth of the Illinois) and at Hannibal, Mo. (above the mouth of the Illinois), measurements were made by the United States Army engineers, covering the year 1882.[1] Several measurements of the Illinois and its tributaries have been made at different points by the United States Army engineers, by the Chicago Drainage Commission, and by other organizations. Rock River, also, has been measured at different points by competent engineers.

ROCK RIVER.

The discharge from this valley has been estimated by Greenleaf from a careful gaging at Milan, a few miles from the mouth of the stream. The ordinary low-water flow is found to be 3,932 cubic feet per second, or 0.36 second-foot per square mile. Greenleaf estimates the average yearly flow to be 9,944 cubic feet per second, or 0.90 second-foot per square mile.

In September, 1895, careful measurements with gage were made below the mouth of the Pecatonica, near the city of Rockford. The measurements were conducted by E. C. Rae, an electrical engineer from Chicago, who was accompanied by the city engineer of Rockford and an expert hydraulic engineer. The results of the measurements are summarized as follows in Mr. Rae's manuscript report to the mayor and city council of Rockford.[2]

Measurements of Rock River near Rockford, Ill.

	Square feet.
Cross section of river	1,487
Speed of water in feet, per minute	41.36
Flow in cubic feet, per minute	61,502

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[1] Report of U. S. Army Engineers, 1883, Appendix TT, pp. 2671-2675.

[2] The writer is indebted to Mr. Daniel W. Mead, C. E., of Rockford, for a copy of the report.

The flow per second is therefore about 1,026 feet, which is only 0.158 second-foot per square mile of area, the area of the portion of Rock River above that point being about 6,500 square miles. Mr. Rae's report also contains the following statements:

> From all appearances, and from the evidence at our disposal, the water was at its lowest stage, and as the rainfall has been below the average during the past eighteen months, *it will be safe to assume that the results obtained in the gagings show the lowest volume likely to occur.* * * * The normal height of the water, however, should be about 2 feet above its surface at the time of gaging, which would of course increase the volume.

The additional 2 feet of depth would increase the flow to about 1,600 cubic feet per second, or nearly 0.25 second-foot per square mile. This may be taken as the ordinary low-water discharge. It is slightly lower than that from the entire basin. Accepting Greenleaf's estimate of the ratio between the ordinary low flow and the average yearly flow (4:10), the latter will be about 4,000 cubic feet per second, or 0.6154 second-foot per square mile of area.

It is thought that the average run-off of Illinois streams will not be greater than that of the upper portion of Rock River, and that it may differ but little from it. In this part of the Rock River basin there is included a variety of drainage which on the whole favors average run-off. It is true that a portion is through swamps and lakes, and a portion through streams with low rate of fall; but a large part is through streams with moderate fall, while in the head-water portions of some tributaries there is as rapid fall as is often met with in Illinois. It is believed, therefore, that the run-off is fully as great as the average discharge from Illinois streams.

A discharge of 0.60 second-foot per square mile is equivalent to 7.282 cubic miles of water per year from the entire State of Illinois. As the annual rainfall of the State, according to Professor Harrington's estimate, amounts to 34 cubic miles, the estimated run-off is about 21 per cent of the rainfall. The rainfall being 38 inches, the estimated run-off is about 8 inches.

This estimate is supported by results from measurements and estimates made in other parts of the country, as may be seen by reference to tables published by Mr. Newell in the Fourteenth Annual Report of the Survey.[1] Mr. Newell estimates that the mean discharge of rivers of small size in the eastern part of the United States is not far from 1.5 to 2 second-feet per square mile, or two to three times that of our estimate for Illinois. In that district the stream discharge is accelerated greatly by the steeper slopes, and also by greater rainfall than in Illinois, which accounts for the greater percentage of run-off.

In a diagram representing the relation of run-off to rainfall[2] Mr.

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[1] Results of stream measurements, by F. H. Newell: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1893, pp. 95-155.

[2] Loc cit., p. 151, fig. 24.

Newell has indicated that for an open country with low slopes, where the mean annual rainfall is 40 inches, a run-off of 15 inches may be expected, while with a rainfall of 30 inches a run-off of about 8 inches is likely to occur; and where the rainfall is 20 inches, only about 3 inches reaches the streams, the quantity, as in the other case, rapidly decreasing with less rainfall. In the case of Illinois, the very low slopes, combined with imperfect development of drainage lines, give results somewhat lower than indicated in the diagram, a rainfall of nearly 38 inches apparently producing a run-off no greater than would ordinarily be expected with a rainfall of but 30 inches.

THE UPPER MISSISSIPPI.

Measurements by the United States Army engineers at Grafton, Ill., show the flow for a year of unusual rainfall, the year 1882. The gage readings range from 31,000 to 392,000 cubic feet per second, with an average of about 150,000. Those at Hannibal for the same year show a range from 17,000 to 292,000 cubic feet per second, with an average of about 111,500. The most important tributary entering the Mississippi between these points is the Illinois, which contributes about 80 per cent of the accession. The discharge of the Illinois for 1882 may therefore be placed at 11,000 to 80,000 cubic feet per second, with an average of about 30,000.

The drainage area of the portion of the Mississippi above Hannibal being about 137,460 square miles (Greenleaf), the run-off ranged from 2⅛ second-feet per square mile to about one-eighth of a second-foot, with an average of about 0.8. On the Illinois, the drainage area being 27,917 square miles, the run-off ranged from nearly 3 second-feet per square mile to 0.4 of a second-foot, with an average of about 1.1.

The year 1882, being one of exceptional precipitation (43.8 inches in Illinois) and being in the midst of a series of years in which the rainfall was above the normal, the run-off is evidently greater than the normal. The above measurements should therefore be considered a maximum yearly run-off rather than a normal one. This is especially true of the Illinois. Gage readings at Kampsville, 30 miles above the mouth of the Illinois, show that the river became bank-full October 4, 1881, and was overflowing or nearly full until July 28, 1882, and that in the last part of the year it was at a low stage (less than 3 feet above low water of 1879) for only twenty-nine days. The average yearly run-off for the Upper Mississippi is probably lower than for Rock River, or not more than 0.6 of a second-foot per square mile of watershed.

ILLINOIS RIVER.

The valley of the Illinois has been made the subject of investigation by the United States Army engineers and by the Chicago Drainage Commission, a commission appointed in 1886 to investigate the subject of the disposal of Chicago sewage. Each organization has given much attention to the question of rendering the Illinois River navigable by supplying it with water from Lake Michigan. A large amount of statistical matter has thus been gathered concerning the regimen of this stream. The statistics pertain, however, not to a stream of normal gradient, but to one which in the lower 225 miles of its course more nearly resembles the Great Lakes than an ordinary river. From these reports such data have been selected as will indicate the regimen of this peculiar river.

Attention has already been called to the river's gradients and the gradients of its tributaries, it being shown that there is a comparatively rapid fall into the lower Illinois from head-water tributaries as well as those which enter its lower course. Professor Cooley has also brought to notice a peculiar grouping of the tributaries. Of the total watershed of the river 11,847 square miles, or 42½ per cent, is above Utica, or in the new portion of the valley, while in the next 86 miles of descent there is an increase of but 12½ per cent; in the following 60 miles 35 per cent is added, leaving only 10 per cent of the catchment area for the lower 65 miles. Concerning the effect of this grouping, Professor Cooley writes as follows:

> Over 80 per cent of the entire watershed lies in two distinct basins, each differing in climatic and topographical conditions, the northern one dominating the valley down to Copperas Creek, or even Havana, the central basin of the State entering the middle section and modifying the lower half of the stream. The lower section is affected sensibly by the fluctuations of the Mississippi.
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> These two basins lie in different storm tracks, so that rain floods may not coincide. The southern basin will usually part with its snow several days sooner in the spring, and more promptly than the northern, as it is more nearly uniform in latitude. Relatively, the floods are probably larger. The sediment from the central basin is doubtless much larger in quantity, as shown by the lower section, which has a much less proportion of deep water and a steeper slope, perhaps ascribable to the influence of the Mississippi in part. Above the Sangamon is a deep pool, and again, Havana Lake, above Spoon River, and finally Lake Peoria, broad and long, the remnant of the ancient stream bed, which demonstrates how little, relatively, has been the detritus from the northern basin, for which the large proportion of marsh and lake sufficiently accounts. These conditions are undergoing change, and the supply of detritus will increase with detrimental effect on all that part of the valley above the Sangamon, and especially above Peoria.

The portion of the lower Illinois above the mouth of the Sangamon has a much smaller prism than the portion below, and Professor Cooley estimates the bank-full capacity at several points as follows:

Bank-full capacity of lower Illinois River.

Locality.	Cubic feet per second.	Remarks.
Peru	18,000-22,000	Measured in 1889. Variation occurs according as river is rising or falling.
Henry	20,000-22,000	Very tentative estimates from dam and prism.
Copperas Creek	18,000-20,000	Do.
Lagrange	30,000	Measured in 1889.
Kampsville	40,000	Estimated from measurements in 1889.

The prolongation of floods in the lower Illinois may be seen by comparing records of overflow with those of points in the upper Illinois. Records at Morris, in the upper Illinois, in the eighteen years from 1871 to 1889 are reported by Professor Cooley to show but 117 days of overflow, or 6½ days per year. At Copperas Creek, on the lower Illinois, the records for the same period (omitting those for 1878, which were not at hand) showed 1,000 days, or 55½ days per year. On the lower section of the lower Illinois the floods are still more prolonged, partly because of influx of water through the Sangamon and partly because of the backwater from the Mississippi. Thus, at Copperas Creek, above the mouth of the Sangamon, in the period from 1883 to 1889, inclusive, the river was out of banks 444 days, or 63½ days per year, while at Lagrange, below the mouth of that stream, it was out 526 days, or 75 days per year. At Morris, for the same period, it was out only 8½ days per year.

Professor Cooley discusses the capacity of the bottoms along the lower Illinois to serve as an impounding area as follows:

> An area of 704 square miles, submerged to a uniform depth of 4 feet—this is a flood height of 16 feet and not an unusual occurrence—represents 1.21 inches of water running off the entire watershed and will supply the river at the rate of 110,000 cubic feet at the mouth for 8.26 days, or at half this volume, which is an approximation to the true maximum discharge, for 16.52 days. An overflow of 8 feet, or a flood of 20 feet, which is an extraordinary occurrence, represents 2.42 inches of water running off the entire watershed, and will supply the river at the rate of 110,000 cubic feet for 16.52 days, or at half the volume for 33.04 days.
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> When it is considered that the water is draining out constantly to the Mississippi, and that the depths of water running off the entire watershed in a brief time must therefore be greater, the conditions are certainly remarkable. An overflow 8 feet deep will supply a bank-full river 21.8 days at Copperas Creek and 36.6 days at Lagrange. The river has been out of banks at these points for 120 days, and for that time a bank-full river at Lagrange will carry 4.8 inches of water from the entire watershed, equal to 5.33 inches of water from the watershed above Lagrange,[1] and the volume flowing in the river course should be greater for the higher stages. Without going into details, it seems as if the volume of water moved mainly in the channel, the bottoms impounding the surplus temporarily until the channel has time to carry it away.
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> In fact, during flood stages the valley is a great lake of, say, 700 square miles, into which flood waters from above and from tributaries are precipitated, and from the lower end of which they run out more at leisure in reduced and equalized volume.
>
> This general consideration explains why floods are higher and less continuous at Lasalle than at points below, as here the upper section of the valley is mainly fed with the land drainage, to be equalized and prolonged in flow through the reservoir action of the bottoms. The central basin acts similarly on the lower half of the valley, and even backs the waters at times on the upper section, and likewise the Mississippi may back it on the lower section. When the upper river has filled the bottoms at Lasalle and has run out, then occurs the slow discharge of the impounded waters southward with a gradual subsidence, and at such time the flow in the upper end of the impounding area is naturally small, and for weeks there is little apparent discharge over the dam at Henry, and at Copperas Creek the action is only less marked.

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[1] A bank-full river at Copperas Creek for 120 days will carry off 5.85 inches of water from the watershed above Copperas Creek.

An illustration of the effects of this impounding area, reported by Mr. E. J. Ward, is found in the flooded stage of the stream in May, 1892. The flood culminated at Morris, May 6, with a discharge of 73,730 cubic feet per second, as determined by an assistant engineer of the Chicago Drainage Commission. It required twelve days for the flood tide to reach the mouth of the river, a distance of only 260 miles, and the flood discharge had increased to 94,760 cubic feet, or only about 21,000 cubic feet per second, as determined by the same engineer. The flood stage at Morris here reported is exceptionally high, being from a drainage area of but 7,360 square miles.

The gage readings at the dams along its lower course show that this portion of the Illinois bears more resemblance to Lake Michigan than to the ordinary streams of this State. It does not show so well as ordinary streams the several alternations of high and low water. On the contrary, it usually maintains high water from the early spring to midsummer, and low water the remainder of the year. Gage readings for Kampsville, Lagrange, Copperas Creek, and other dams are presented by Capt. W. L. Marshall in the report of the United States Army engineers, 1890. The following table of average monthly means, based upon the daily gage readings at the Copperas Creek dam for the years 1879 to 1889, inclusive, serves to illustrate the above statement:

Table showing monthly means of gage readings above and below Copperas Creek dam for eleven years, 1879 to 1889, inclusive.[1]

Month.	Above dam.	Below dam.
	Feet.	*Feet.*
January	9.10	12.31
February	10.42	14.37
March	12.59	17.15
April	11.93	16.50
May	10.44	14.43
June	9.68	13.45
July	8.44	11.44
August	7.25	8.55
September	7.02	7.58
October	7.30	8.52
November	8.04	10.07
December	8.39	11.01
Annual	9.22	12.11

[1] Report of Capt. W. L. Marshall, U. S. Army Engineers, vol. 3, 1890, pp. 2525–2531.

From the above table it appears that on the Illinois a minimum flow is reached in September, near the close of the summer drought. On

Lake Michigan there is but the one fluctuation, but the lowest stage is in February, when the tributaries are frozen and precipitation is low, as may be seen by the following table:

Table showing mean stages of Lake Michigan above Chicago city datum, for thirty years, 1860 to 1889, inclusive. *

Month.	Mean stage.	Month.	Mean stage.
	Feet.		*Feet.*
January	1.573	July	2.503
February	1.562	August	2.455
March	1.731	September	2.290
April	1.935	October	2.051
May	2.192	November	1.803
June	2.428	December	1.572

* Table by L. L. Wheeler, assistant engineer; Rept. U. S. Army Engineers, vol. 3, 1890, p. 2517.

The average run-off at the Copperas Creek dam for the eleven years, 1879 to 1889, inclusive, has been estimated by Prof. L. E. Cooley, from gage readings, to be 10,500 cubic feet per second.[1] The drainage area of the Illinois above this dam is estimated to be 15,250 square miles. The run-off is therefore about 0.688 second-foot per square mile, or very nearly the same as Greenleaf's estimate for the entire basin (0.654 second-foot per square mile). The normal rainfall for the Illinois basin is about 37 inches, of which, as estimated by Greenleaf, 24 per cent, or 8.88 inches, escapes by the stream. As indicated above, this is probably not far from the average run-off for the State.

The low-water volume of the Illinois is exceedingly small, as may be seen by the following statistics compiled by Professor Cooley:

> In 1888 the water running over the Henry dam was less than 500 cubic feet per second for 9 days and at Copperas Creek for 20 days. The water at Copperas Creek was at or below the same level in 1887 for 117 days; in 1886, 18 days; in 1879, 44 days; at Henry in 1877, 30 days; in 1875, 47 days, and in 1871 apparently for a longer period. The volume in 1888 was less than that sent through the canal at Chicago for the same period (about 700 cubic feet per second). Lake water from 300 cubic feet upward has been going to the valley ever since July, 1871.[2]

Professor Cooley states that the amount of leakage through the dams at these times is not known. He estimates that since the Bridgeport pumps were erected in 1883 over half the minimum discharge of the portion of the valley above the mouth of the Sangamon has come from Lake Michigan, and about one-third below the mouth of the Sangamon. The river was measured in 1887 at low-water stage at Lagrange, below

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[1] *Lake and Gulf Waterway*, by L. E. Cooley, p. 65.

[2] Ibid, p. 64.

the mouths of all the large tributaries, and found to have a discharge of but 1,685 cubic feet per second.[1] Assuming Professor Cooley's estimate of one-third as due to influx from Lake Michigan, and allowing a slight addition for small tributaries below Lagrange, we have about 1,200 feet as a low-water discharge of the Illinois, a discharge of but 0.043 second-foot per square mile of area. .

Summing up results of measurements, it appears that in a wet season the stream discharges range from 0.40 to 3 second-feet per square mile of area, with an average of 1.1 second-feet. In an ordinary season the average discharge is about 0.65 second-foot per square mile. In a season of drought the low-water discharge is but 0.043 second-foot per square mile.

Kankakee River.—Measurements and estimates of the flow of the Kankakee have been made at Wilmington, near the mouth of the stream, by Mr. E. S. Waters, for the period of twelve years ending in 1883. The following statements of results of Mr. Waters's observations are presented by Professor Cooley, in a report to the State board of health.[2]

Volume of the Kankakee River at Wilmington, Ill.

	Cubic feet per second.
Extreme high-water stage	30,000-35,000
Ordinary low-water stage	1,300
Extreme low-water stage	420

This stream, as already noted, is remarkably regular in its flow, because of the great marsh, which acts as a storage reservoir and constant feeder for the lower course. The lowest stages of the river occur when in severe winters the marsh is frozen so solid as to prevent the escape of water to the river.

The ordinary low-water discharge of this river is but 0.25 second-foot per square mile of area, but the average run-off probably reaches that of the entire upper basin of the Illinois (0.688) if it does not exceed it. The period covered by the observations includes both dry and wet years, and probably represents well the ordinary low discharge.

Des Plaines River.—This stream has had an exceptionally interesting history. During the activity of the southwestward outlet of Lake Michigan it was tributary to the lake, entering it at first about 2 miles north of Riverside. As the lake level lowered, the mouth extended south until it reached the site of Riverside. After the outlet was abandoned two courses lay open to the stream, either east into the lake or southwest along the old outlet, for its point of entrance is near the summit in the old outlet. In flood stages the water rose above the level of the summit, and the stream consequently flowed in both directions. It is thought by Professor Cooley that the main discharge of the river for the greater part of the time since the southwestward outlet

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[1] Report U. S. Army Engineers, vol. 3, 1890, p. 2443.

[2] Prel. Rept. State Board of Health, on Water Supplies and Pollution of Streams, 1889, p. 79.

was abandoned by the lake has been into Lake Michigan, the southwestward course being occupied only in flood stages. Its present regimen is just the reverse. This opinion of Professor Cooley's is based upon the very small channel cut by the stream in its present course down the outlet. The change to the present course he thinks to be due to an accumulation of the river silts in the lakeward course to such a height as to prevent the low-water flow from taking that course.[1] But at high-water stages it still spreads out to the eastward along the old outlet (now forming an inlet to the lake), and much of its flood enters Lake Michigan.

The Des Plaines has been found to have at Riverside an extreme flood stage of about 10,000 cubic feet per second, with an occasional higher volume, as in April, 1881, when it reached 13,500 cubic feet. It has been estimated by Professor Cooley that, on an average, once in five or six years during the past fifty years the flood has exceeded 10,000 cubic feet, while the ordinary yearly flood, as shown by marks on a dam at Lyons, just below Riverside, is 6,000 to 7,000 cubic feet per second. In these extreme floods nearly half the water has been wont to discharge into Lake Michigan, and in ordinary floods a small discharge has usually occurred.[2]

As a consequence, the flood stages of the Des Plaines are higher above Riverside than those of the lower course of the stream. Professor Cooley estimates the normal extreme flood at Joliet to be but 6,300 feet. At a flood stage in June, 1892, however, the discharge on the lower Des Plaines at Joliet reached 10,500 cubic feet per second (E. J. Ward).

The drainage area above Riverside is scarcely 1,000 square miles. This gives at the maximum extreme flood of April, 1881, a flow of fully 13.5 second-feet per square mile of area. The low-water volume is exceedingly small. Professor Cooley reports that at Riverside, in 1887, it reached a minimum of 4.27 feet per second, and for five months did not exceed 16⅔ cubic feet per second. He estimates that for nearly every year the extreme low water at Riverside and Joliet reaches about 5 cubic feet per second.[3]

The main tributary of the Des Plaines, the Dupage River, as noted by Professor Cooley, drains a more gravelly tract than the Des Plaines and receives water from springs, so that it sustains a larger low-water flow than the upper Des Plaines, but its extreme low-water flow is still very small; it is estimated by Professor Cooley to not exceed a mean of 50 feet per second in a period of twenty years, and possibly reaches as low as 17 to 20 feet per second in some years.[3] The greater percentage of range of the Des Plaines, as compared with the main

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[1] The Illinois River in its relations to sanitary engineering, L. E. Cooley, C. E.: Prel. Rept. Ill. State Board of Health, 1889, pp. 54-55.

[2] Loc. cit., pp. 72-73.

[3] Loc. cit., p. 74.

stream, the Illinois, illustrates a general rule in streams which has been well expressed by Cooley as follows:[1]

> The flood volume of a stream is never equal to the combined volumes of the tributaries, and with many tributaries and a large area does not even approach such a volume. The several tributaries will not reach high water at the same time, nor will their floods reach the main stream conjointly; neither do they enter at the same point, but are distributed along the valley. The practical result is that the duration of the flood in the main stream is much lengthened, and the volume is correspondingly less than the aggregate of the tributaries. Alteration in the flood conditions of the tributaries will not materially change the time or order in the contribution to the main stream, and as the results are only partially cumulative the effect is relatively less. In many large basins no sensible change would probably occur.
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> The reverse is true in a less degree of the low-water volumes. No two tributaries are in exactly the same condition as to low water at exactly the same time, but as the low-water period is very much longer than that of floods, the results are more nearly cumulative. It is found practically that the low-water volume in small basins is less per square mile than in large ones.

Fox River.—The run-off from Fox River, as reported by Greenleaf from measurements by United States Army engineers, is 526 cubic feet per second, or 0.195 second-foot per square mile of its drainage basin. This is thought to be the ordinary low-water discharge. Greenleaf further states that those familiar with the stream claim that it has fallen off one-half in its low-water volume since the clearing and cultivating of the land and the draining of the swamps.

Sangamon River.—The Sangamon River is subject to great variations in volume, there being in the annual flood stages a rise sufficient to overflow banks 8 to 12 feet in height. The river at such times, being a swift stream, probably discharges not less than 15,000 cubic feet per second, and in extreme floods the discharge probably exceeds 20,000 cubic feet per second.

At low water the discharge, as estimated by Professor Cooley, drops to about 350 cubic feet per second. Professor Cooley estimates that the low-water discharge of the lower Illinois is increased about 600 feet by the contributions from the Sangamon and Spoon rivers and Crooked Creek.[2] The Sangamon carries about four-sevenths of this discharge, or about 350 cubic feet, leaving a low-water discharge of less than 200 feet for Spoon River and less than 100 feet for Crooked Creek. As the Sangamon is subject to low stages for a considerable part of the year, its efficiency is to be measured by the low-water flow rather than the average discharge. The average discharge is probably low because of the imperfect drainage lines of its upper course.

STREAMS OF SOUTHERN ILLINOIS.

So far as known to the writer, no accurate gagings of the streams of southern Illinois have been made. No cause for a wide variation from the percentage of run-off in the streams of northern Illinois has,

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[1] Loc. cit., p. 57.

[2] Lake and Gulf Waterways, p. 65.

however, been recognized. The southern district has probably a slightly higher rate of evaporation, which would tend to lessen the amount of run-off; but it has, on the other hand, a more perfect system of drainage, which would tend to increase the percentage of run-off. Similarly, the lesser relief of the southern Illinois district tends to lower the run-off, but the greater perfection of drainage tends to increase it. The run-off of between six and seven tenths of a second-foot per square mile of watershed area, found for the Rock and Illinois, seems likely to be shown also by streams of southern Illinois.

CHAPTER IV.

NAVIGABLE WATERS.

The State of Illinois has possibilities in navigation not excelled by any other State so far removed from the seaboard. Touching as it does upon Lake Michigan, it is connected with the Eastern seaboard, and, bordered as it is by the Mississippi, it is connected with the Southern States and the Gulf of Mexico, and also with States to the north. On the Ohio, also, it is connected with a navigable waterway eastward to Pittsburg. Through the midst of the State passes the Illinois River, which, by the aid of dams and locks in its lower course, has been made navigable in ordinary low water as far as Peru for small river vessels. From Peru to Chicago the Illinois and Michigan Canal affords passage for canal boats between Lake Michigan and the Illinois.

The lower Illinois River at very low stages has but 1½ to 2 feet of water on the bars. At such times navigation must of course be suspended. The present dams and locks are of service only at ordinary low water. It is evident that the present system of navigation by dams and locks interferes with rather than aids the stream in its effort to form a channel adapted to the small volume of water which it has carried since the lake outlet was abandoned. Any obstruction to the flow must decrease the effective work of the stream. Measures looking to an increase of volume in the river seem to be the natural remedy. For some years such measures have been under consideration, both by the United States Army engineers and by the Chicago Drainage Commission. Work was begun in 1892 on a large channel which will extend from Lake Michigan southwestward through Chicago and along the line of the abandoned lake outlet to Joliet. A sanitary district was organized in 1890 under the general law for incorporating sanitary districts enacted by the Illinois legislature in 1889, and is known as the Sanitary District of Chicago. From its last report (April, 1895) the following statistics concerning the channel have been gathered: The channel is excavated partly in earth and partly in rock. The grade in the earth portion, which leads from Chicago nearly to Lemont, is 1 foot in 40,000, while in the rock section it is 1 foot in 20,000 feet. The bottom of the channel at its lakeward end is to be 24.448 feet below the city datum (which was extreme low water in Lake Michigan in 1847 and 578.56 feet above mean tide in the Gulf of Mexico). The channel has in the rock section a capacity of 10,000 cubic feet per second. The southwestern terminus will be near Lockport, where the channel enters the Des Plaines River. Controlling works will be constructed at that point for conducting the flow from the channel, in conjunction with the waters of the Des Plaines River, down the declivity through the city of Joliet. When completed, this channel will be a free waterway navigable for any vessel drawing less than 22 feet of water. The cutting to be made by the sanitary district is estimated to cover about two-thirds of the entire cost of a channel from Chicago to the Mississippi which would be navigable for the largest boats able to ply between St. Louis and New Orleans. The expense assumed by the sanitary district is about $21,600,000, of which nearly $13,000,000 had been expended at the date of the last report, April 1, 1895.

The commercial value of such a channel will no doubt lead sooner or later to its completion and give to the State of Illinois one of the greatest waterways of this country.

A small canal is under construction which will connect the Mississippi at Rock Island with the Illinois at Hennepin, known as the Hennepin Canal. The feeder will be Rock River, and will lead southward from a point near Dixon. The restrictions in the volume of water obtainable through this feeder will necessarily prevent the opening of a canal of great size, but it promises to afford navigation for the small vessels which now ply the Upper Mississippi and the Illinois.

The construction of a canal past the lower rapids on the Mississippi near Keokuk has rendered that stream navigable in low stages as far as St. Paul, for the upper rapids are usually navigable for such boats as are in use between St. Paul and St. Louis—boats which do not draw more than 6 feet of water.

CHAPTER V.

WATER POWER.

In his report for the Tenth Census, Prof. J. L. Greenleaf has discussed in considerable detail the water power of Illinois streams, with the exception of those tributary to the Wabash.[1] As the present writer has made no special study of water power, he will only review briefly the results given by Professor Greenleaf in the light of a study of the physical features.

The northern part of the State is shown by Professor Greenleaf to be far better fitted than the southern for the utilization of water power. The streams of the northern portion have, on the whole, a more rapid descent than those of the southern portion, because of the generally greater relief of that part of the State above the main valleys. The discharge of streams is also more uniform in the northern portion because of a loose-textured drift which absorbs the rainfall and feeds the streams through seasons of drought, and because of marshes and lakes which also serve to impound water and feed the streams in dry seasons. A striking contrast is therefore found in the use of water power. In the northern portion of the State not only the large streams, such as the Kankakee, Fox, Rock, Kishwaukee, and Pecatonica, have mills using water power, but smaller streams, such as Apple Creek, Yellow Creek, Sugar Creek, Carroll Creek, Elkhorn Creek, Rock Creek, and Piscasaw Creek—streams whose gathering grounds are but a few hundred square miles in extent—also afford power which is used by mills throughout most of the year. The only important exception in northern Illinois is Green River, a tributary of Rock River, which, with a watershed of 1,131 square miles, drains a large swampy basin and has a sluggish stream with low banks. This stream naturally has no developed water power.

In western Illinois, Spoon River, a tributary of the Illinois, has several mills using water power which is ordinarily sufficient for milling purposes. Edwards and Henderson rivers and Pope Creek, tributaries of the Mississippi, have mills using water power, but the power is rather uncertain because of floods and very low stages.

From the Illinois River southeastward the use of water power is largely abandoned. Vermilion River, Sangamon River, Kaskaskia River, and

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[1] The water powers of the Mississippi and some of its tributaries, by J. L. Greenleaf: Tenth Census of the United States, Vol. XVII, 1880, pp. 119-276.

other streams upon which mills using water power were constructed in pioneer days, have scarcely any mills remaining. The poor sites for dams in deposits of clay or sand, the great variation of water height, and the comparatively low fall of streams, combine to make the water power of little value to the miller or the manufacturer. The Big Vermilion, a tributary of the Wabash, has several mills using water power, though in some cases not entirely dependent upon it. This stream is well calculated in its lower course, by rapid fall and by rocky beds and banks for dam foundations, to furnish power, and the high stages are less liable than are streams of lower rate of descent to produce back water; but it is subject to very low stages, in which the discharge is insufficient to produce the power necessary to run the mills.

CHAPTER VI.

WATER SUPPLIES FOR CITIES AND VILLAGES.

GENERAL STATEMENT.

Throughout much of Illinois several sources of water supply are available for domestic use. Chicago and the smaller cities bordering Lake Michigan may obtain water from the lake, from artesian wells, or from shallow wells. The cities along the main streams, with the exception of those on the lower Des Plaines and the Illinois, where the water is contaminated by sewage, may generally use the stream water with safety. In addition to this they have usually an available supply of good water from wells of slight depth, and in much of northern and western Illinois a fair quality of water may be obtained from artesian wells. The cities not located near large streams or the lake, resort in some cases to storage reservoirs, formed by damming small streams, for a part of their supply, but the greater number depend entirely upon wells, and of these wells but few are artesian. In rural districts and in the villages which have no waterworks the supply is mainly from shallow wells, though deep wells are not rare.

A study of the development of the water supply in cities shows that they have, in the early days, almost without exception, used shallow wells, but with the growth of the city often these either have become inadequate or are found to be contaminated. A change is then made to streams, if these are available, and if not deep wells are sunk. In a few places, however, among which Peoria is a conspicuous instance, there has been a return to shallow wells because of the unpleasant taste of water from deep wells.

In addition to the sources named, a large amount of the water supply is from cisterns which collect the rain water from the roofs of dwellings or other buildings. Inasmuch as the well water and stream water are usually so strongly charged with lime as to be too hard for laundry purposes, rain water is in demand in both city and country. Cisterns are the main dependence in a few small districts, notably the driftless portions of the State and places where the drift is thin. In places where the drift, though thick, contains a very small sandy ingredient and few sand pockets or beds, good wells are so difficult to obtain that cisterns have come into use for all domestic needs. These districts are small, however, comprising scarcely one-tenth the area of the State. The drift usually affords abundance of excellent water at convenient depth.

SURFACE WATER.

The extent to which surface water is used may perhaps be best shown by a list, nearly complete, of the cities and villages in which this is the chief source of supply. With the source of supply are included statistics concerning the cost of waterworks and systems used; also the running expenses per annum. In most instances these have been furnished by the officers in charge of the waterworks.

The increase in the population since the last census was taken (in 1890) has been more rapid in Chicago and some of the other leading cities than in the villages and rural districts. There is, therefore, a larger proportion of the population in these cities, and consequently a larger proportion using surface water now than in 1890. In 1890, with a total population of 3,826,351, there were probably 1,375,000 people, or slightly more than one-third, using surface water. It is estimated that the present population is about 4,500,000, and that 1,800,000, or about two-fifths of the population, depend mainly upon surface water.

The State board of health has made analyses of water used by several of these cities, and they may be found in the tables of sanitary analyses given later in this paper. There is usually but little contamination from city sewage. The Chicago intakes are affected by sewage only when the Chicago River is at high stages, which seldom amounts to more than a few days each year. At such times it becomes necessary to boil the water before drinking. Cities located upon streams usually obtain water at points above where the sewage enters.

Cities and villages using surface water.

Place.	Population in 1890.	Source.	Waterworks.	
			Cost *a*.	System.
Alton	10,294	Mississippi River	(?)	Pump to standpipe or direct.
Cairo	10,422	Ohio River and wells	$125,000 Ex. 20,000	Pump to standpipe; Herdic system.
Carlinville	3,293	Macoupin Creek	(?)	(?)
Carlyle	1,784	Kaskaskia River	35,000 Ex. 1,000	Pump to standpipe.
Centralia	4,763	Crooked Creek and wells.	45,000 Ex. 2,500	Direct pressure.
Charleston	4,135	Embarras River	40,000 Ex. 3,000	Do.
Chicago	1,099,850	Lake Michigan	(?)	Tunnel and pumps.
Danville	11,491	North Vermilion River.	(?)	Pump to standpipe.
Decatur	16,841	Sangamon River	200,000 Ex. 25,000	Holly system (direct).
Dundee	2,023	Springs	40,000 Ex. 800	Hydraulic ram to reservoir.
East St. Louis	15,169	Mississippi River	(?)	Holly system.

a "Ex." in this column means running expenses per annum.

Cities and villages using surface water—Continued.

Place.	Population in 1890.	Source.	Waterworks.	
			Cost [a].	System.
Elgin	17,523	Fox River	$173,622 Ex. 8,766	Pump to standpipe and direct.
Evanston	12,762	Lake Michigan	124,000 Ex. 7,300	Holly system.
Highland Park	2,163	do	60,000	Dean pumps.
Hillsboro	2,500	Group of springs	18,000 Ex. 400	Elevated tank; also direct pressure; Worthington pump.
Kankakee	9,025	Kankakee River	100,000	Pump to standpipe.
Lake Forest	1,203	Lake Michigan	(?)	
Lincoln	6,725	Salt Creek	40,000	Do.
Litchfield	5,811	Shoal Creek	50,000 Ex. 2,000	Reservoir on creek; Holly system.
Metropolis City	3,593	Ohio River	40,000	Dean pumps.
Moline	12,000	Mississippi River and artesian wells.	(?) 44,270 Ex. 11,878	Direct pressure.
Morrison	2,088	Natural spring	40,000 Ex. 2,500	Reservoir; direct pressure.
Mount Vernon	3,233	Creek reservoir	(?)	(?)
Murphysboro	3,880	Big Muddy River	60,000 Ex. 4,000	Pump to standpipe.
Newton	1,428	Embarras River	[b] 5,000	Direct pressure.
Olney	3,831	Fox River and wells	4,000	Pump to standpipe.
Oregon	1,566	Rock River	15,000	Pump to reservoir.
Ottawa [c]	9,985	Springs	(?)	Reservoir in South Ottawa from springs.
Pecatonica	1,059	do	(?)	Pump from reservoir to standpipe.
Quincy	31,494	Mississippi River	(?)	Pump to filter gallery, then to mains and reservoir.
Rochelle	1,789	Springs in quarry	Ex. 486	Pump to standpipe.
Rock Island	13,674	Mississippi River	35,000	Holly system (direct pressure); standpipe for elevated part of city.
Shelbyville	3,162	Kaskaskia River	60,000	Pump to standpipe.
Springfield	24,963	Sangamon River	(?)	Gallery system from river, with direct pressure.
Staunton	2,209	Dam on brook	39,000	Pumped from reservoir on brook.
Streator	11,414	Vermilion River	(?)	Pump to standpipe and direct pressure.
Venice	932	Mississippi River	(?)	Pumped in open reservoir.
Waukegan	4,915	Lake Michigan	60,000 Ex. 4,000	Dean pumps.
Wilmington	1,576	Kankakee River	10,000	Direct pressure (Holly system).
Winnetka	1,079	Lake Michigan	(?)	Pump to water tower.
Yorkville	375	Springs in moraine	6,000	Gravity to reservoir.

[a] "Ex." in this column means running expenses per annum.

[b] Cost of pumping station, etc., exclusive of laying mains.

[c] Derives water from about 200 artesian wells.

SHALLOW WELLS IN VALLEYS.

Several cities obtain their water supply from shallow wells which in some cases reach no lower than the alluvial deposits of the valley, though in other cases they pass into glacial deposits beneath the level of the stream bed. Those cities which obtain a supply from alluvium usually take the precaution to locate the waterworks wells above the city, where the danger from contamination will be at a minimum. Those whose wells enter glacial deposits have not in all cases taken this precaution. For example, Pekin has its waterworks in the lower end of the city. The wells are using water from a level below the Illinois River, and probably receive but little contamination from city sewage and filth. There is, however, no thick bed of clay or impervious stratum above the beds which yield the water. In Bloomington, also, the wells are located near the central part of the city, where contamination may occur, though the clay cover would seem to be a sufficient protection. At Peoria the waterworks are located above the city and the water-bearing bed is overlain by bowlder clay; there seems, therefore, little danger of contamination at that point.

The villages which have no waterworks, and hence derive their supply from the wells located within the village boundaries, are, on the whole, more liable to suffer from water pollution than the towns having waterworks. The writer has noted instances where the village authorities have been so unwise as to put down wells at public-school buildings on the downstream side of the privy vaults, sometimes within 50 feet of the vaults. Such ignorance or rashness can not be too strongly condemned.

In the following table, which embraces towns deriving water from shallow wells in valleys, the character of the cover is indicated:

Cities and villages using shallow wells in valleys.

Place.	Population in 1890.	Depth.	Water bed.	Cover.	Waterworks.	
					Cost. *a*	System.
		Feet.				
Algonquin	(?)	2- 20	Gravel	Gravel		None.
		60- 80	do	Till 40 feet		
Amboy	2,257	12- 20	Gravel and rock	Gravel or sand		Not from shallow wells.
Aurora	19,688	20- 40	Gravel	Mainly gravel		Do.
Beardstown	4,226	30	do	Sand	$35,000	Pump to standpipe.
		W. W. 50 +	do	Gravel		
Belleville	15,361	42	do	Till 40 feet	(?)	Do.
Bloomington	20,484	65	do	Blue clay 32 feet	200,000 Ex. 9,000	Pump to standpipe, and direct.
Chillicothe	1,632	40- 80	do	Gravel		(?)
Chester	2,708	River level	Sand	Sand		None.
Dallas City	747	10- 32	Sand or limestone	Clay or limestone		Do.
Dundee	2,023	River level	Gravel	Gravel		Not from shallow wells.
Equality	622	30- 40	Clay and clay shale	Clay		None.
Erie	535	18- 30	Fine gravel	Clay 2-11 feet		Do.
Forrest	1,021	10- 12	Gravel	Brown clay		Do.
		25- 30	do	Blue clay 16-18 feet		
Freeport	10,189	44	Sand	Alluvium	(?)	Pump to standpipe, and direct.
Golconda	1,174	30- 40	Rock	Limestone or sandstone		None.
Grafton	927	20- 35	Sand or gravel	Clay and gravel		Do.
Havana	2,525	74	Sand and gravel	Clay 10 feet	32,000 Ex. 3,100	Dean pumps.
Hennepin *b*	574	100	Coarse gravel	Loam and clay 50 feet; gravel 50 feet.		None.
Henry	1,512	60- 70	Sand	(?)		Do.
Hutsonville	582	9- 30	Sandstone	Sandstone		Do.
Joliet *b*	23,264	35	Gravel	Clay, 6 feet		Not from shallow wells.

Kankakee	9,025	20- 40	....do	Clay or gravel		Do.
		30- 50	Limestone			
Keithsburg	1,484	20- 50	Sand	Clay, 1-8 feet	(?) Ex. 1,000	Holley system.
Lasalle *b*	9,855	5- 40	Sand and gravel	Variable; pervious		Not from shallow wells.
Lawrenceville	865	12	Sand	Clay		None.
Lewistown *b*	2,166	20	....do	Sand	Ex. 1,200	Pump to standpipe.
Marengo	1,445	20- 25	Sand and gravel	Sand and gravel		Not from shallow wells.
		125	....do	Clay, etc		
Marseilles *b*	2,210	25- 30	Gravel	Gravel		Do.
		100-200	Sandstone	Sandstone, etc		
Momence	1,635	12- 30	Limestone	Limestone		None.
Mount Carmel *b*	3,376	25	Sand and gravel	Sand and gravel	65,000 Ex. 3,600	Dean pumps to standpipe; also direct.
Naperville	2,216	20- 40	Gravel	Yellow and blue clay		None.
Oregon *b*	1,566	30	Sand and gravel	Sand and gravel		Not from shallow wells.
Pekin *c*	6,347	80	....do	Thin clay bed	(?)	Pump to standpipe.
Peoria *c*	41,024	50	Gravel	Bowlder clay	(?)	Standpipe and Worthington pumps.
Petersburg	2,342	25- 00	Sand	Clay, 15 feet	19,000 Ex. 1,500	Pump to standpipe.
Shawneetown	2,620	25- 40	Gravel	Clay and gravel		None.
Taylorville	2,829	20- 40	Sand	Clay, 20 feet	20,000	Holley system.
Thebes	673	20	....do	Sand and clay		None.

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a "Ex." in this column means running expenses per annum.

b Many shallow wells in use, though the waterworks have another source of supply.

c Breweries use water from Illinois River or from artesian wells. Pekin City Park has a 1,000-foot well.

WELLS IN GLACIAL DRIFT.

A large number of cities and villages obtain their entire supply of water from the glacial drift. In the following table, which embraces the principal towns depending upon such wells, the character of the water bed and of the cover is shown. The water-bearing beds have in most of these towns proved adequate, and usually supply a good quality of water, superior either to surface water or to water from wells in the rock. It will be observed that a few cities are included in this list which have populations of several thousand each.

Cities and villages using wells from glacial drift.

Place.	Population in 1890.	Depth.	Water bed.	Cover.	Waterworks.	
					Cost. *a*	System.
		Feet.				
Alpha	200	15- 30	Gravel	Mainly loess		None.
Arcola	1,733	102	Sand and gravel	Till	(?)	Pump to standpipe.
Astoria *b*	1,357	20- 40	Sand	Yellow and blue till		None.
Atlanta	1,178	W. W. 151	Sand and gravel	Till	(?)	Pump to standpipe.
Augusta *b*	1,077	20- 60	Gravel or sand	Mainly till		None.
Avon *b*	692	20- 40	Sand or shale	do	(?)	Pump to tank on mill.
Bement	1,129	W. W. 150	Sand and gravel	do	$13,000 Ex. 600	Fairbanks system.
Blue Mound	696	15- 40	do	do	6,000	Pump to small tank.
Braceville	2,150	30- 40	Sand	Sand		None.
Braidwood *b*	4,641	8- 18	do	do	(?)	For fire purposes only.
Bunker Hill *b*	1,269	20- 30	do	Blue till		None.
Bushnell	2,314	W. W. 115	Gravel	Mainly till	30,000	Pump to standpipe and direct.
Caledonia *b*	184	20- 40	Clay	Till		None.
Cambridge *b*	940	35- 75	(?)	Mainly till		Do.
Camp Point *b*	1,150	25- 30 45- 50	Till or gravel	do		Do.
Carbondale *b*	2,382	15- 20	Clay	Mainly loess		Do.

Casey	844	18- 60	(?)	(?)		Under construction.
Centralia *b*	4,763	11- 30	Clay or gravel	Till	45,000 Ex. 2,500	Direct pressure.
Champaign with Urbana.	9,350	157-162	Sand and gravel	Mainly till	175,000 Ex. 12,000	Do.
Charleston *b*	4,135	20- 40	do	Blue clay		Not from drift wells.
Chatsworth	827	15-100 W. W. 65	do	Till	8,000	Windmill and tank.
Coal City	1,672	8- 10	Sand	Sand		None.
Clinton	2,598	56-120	Sand or gravel	Till	(?) Ex. 3,000	Holley system.
Delavan	1,176	W. W. 160	Sand and gravel	Mainly till	30,000	Standpipe or direct pressure.
Duncanville *b*	(?)	18- 20	Sand	Till		None.
Du Quoin *b*	4,052	15- 40	(?)	Mainly till		Do.
Dwight	1,354	W. W. 135	Gravel	do	15,000 Ex. 1,800	Dean pump, direct pressure.
Earlville *b*	1,058	30- 60	do	Till		Not from drift wells.
Edwardsville	3,561	20- 80	Till	do		None.
Effingham *b*	3,260	18- 20	Till and shale	do		Do.
Elmwood	1,548	25- 40	(?)	Mainly till		Under construction.
Elpaso	1,353	W. W. 105	(?)	do	20,000 Ex. 1,000	Pump to tank.
Elvaston	307	12- 30	Gravel	Till		None.
Eureka	1,481	15-105	do	Sand and gravel	10,000	Holley system.
Farmer City	1,367	W. W. 176	Sand	Mainly till		Pump to standpipe.
Forreston *b*	1,118	25 35- 40	Gravel (?)	Clay Till	8,000 Ex. 400	Not from drift wells.
Gardner	1,094	20- 30 40- 50	Gravel and sand	Mainly till		None.
Galesburg	15,264	W. W. 70- 80	Sand	Mainly sand	100,000	Direct pressure.
Genoa	634	25- 60	Sand and gravel	Mainly till		None.

[a] "Ex." in this column means running expenses per annum.

[b] Occasional wells are in the rock.

Cities and villages using wells from glacial drift—Continued.

Place.	Population in 1890.	Depth.	Water bed.	Cover.	Waterworks.	
					Cost.[a]	System.
		Feet.				
Gibson City	1, 803	18- 24 40- 45 86-110	Sand	Variable	$30, 000	Tower and reservoir; Dean pumps.
Gilman	1, 112	12- 16 75-150	do	Mainly till		None.
Greenfield	1, 131	18- 30	Gravel and clay	Loess and till		Do.
Greenville	1, 868	W. W. 35	Sand and gravel	Clay	16, 000	Direct pressure.
Hamilton[b]	1, 301	20- 30	Sandy clay	Loess and sand		None.
Harvard[b]	1, 967	35 ±	Gravel	Clay	(?)	(?)
Hillsboro[b]	2, 500	15- 62	Sand	Variable		Not from drift wells.
Hoopstown[b]	1, 911	80-160	Mainly gravel	Sandy clay		Do.
Indianola	472	20- 40	Sand and gravel	Mainly clay		None.
Kansas	1, 037	8- 40	Blue clay	Mainly till		Do.
Laharpe	1, 113	100	Sand	Mainly till, 60 feet	(?)	(?)
Lanark	1, 295	85- 90	Gravel and sand	Mainly till, 75 feet	(?)	Standpipe.
Lebanon[b]	1, 636	30- 40	Gravel	Mainly till		None.
Leroy	1, 258	W. W. 110	Sand	do	7, 000 Ex. 500	Pumped to tower.
Litchfield	5, 811	25- 40	(?)	do	50, 000 2, 000	Not from drift well.
Macon	819	120	Sand and gravel	do		(?)
Marion	1, 338	20	Sand	Clay		None.
Maroa	1, 164	W. W. 100 ±	Gravel	Blue till	12, 000	Elevated tanks; also steam pressure.
Martinsville[b]	779	15- 20	Clay and sand	Mainly till		None.
Mason City	1, 869	35	Sand and gravel	Sandy clay	(?)	(?)
		130	do	(?)		

Mattoon	6,833	15- 30 W. W. 60- 70	do do	(?) Blue till	(?)	Pump to standpipe and direct.
Mendota [a]	3,542	12- 20	Clay and sand	Till		Not from drift wells.
Metamora	758	40- 85	(?)	(?)	(?)	Pump to tank; gasoline engine.
Monticello	1,643	W. W. 212 and 316	Sand and gravel	Till and sand	26,000 Ex. 1,000	Pump to tank, and direct pressure.
Morrisonville	844	25- 30	Sand	(?)	(?)	Standpipe with force pump.
Mount Pulaski	1,357	30	Sand and gravel	Loess and till		Under construction.
Mount Sterling [b]	1,655	16- 25	Sandy clay	Mainly loess	(?)	(?)
Nauvoo [b]	1,208	12- 40	do	Loess, sand, and clay		None.
Neoga	829	17	Sand	Loess and till		Do.
Normal	3,459	26	Gravel	(?)	(?)	(?)
Oakland	995	20	Sand	Blue clay		None.
Odell [b]	800	30-168	Gravel	Mainly blue till		Do.
Olney [b]	3,831	12	do	Silt and till		For fire purposes from Fox River.
Onarga	994	10- 20 90-160	Sand Gravel	Sand Blue till		Under construction.
Pana	5,077	18- 48	Sand and gravel	Mainly till	44,000	Pump to standpipe.
Paris	4,996	60	Sand	Clay 50 feet	(?) Ex. 10,000	Blake, Worthington, and Cook pumps.
Paxton	2,187	W. W. 150	Sand and gravel	Mainly till	(?)	Elevated tank.
Plano (Mead)	1,825	16	Gravel	Blue clay	(?)	(?)
Polo [b]	1,728	30	do	Loess and till	18,000 700	Not from drift wells.
Rantoul	1,074	80-200	Gravel and sand	Mainly till	25,000	Direct pressure.
Ridgefarm	757	10- 20	Sand	Till		None.
Roodhouse [b]	2,360	14- 24	Gravel	do		Do.
Rushville [b]	2,031	16- 30	Clay	Loess and till		Not from drift wells.
Salem	1,493	20	Sandy clay	Mainly till		None.
Sandoval	834	14- 18	Blue sandy clay	do		Do.
Sandwich	2,516	W. W. 110 20- 35	Sand and gravel Gravel	Thin clay beds with sand and gravel.	25,000	Pump to standpipe.

[a] "Ex." in this column means running expenses per annum.

[b] Occasional wells are in the rock.

Cities and villages using wells from glacial drift—Continued.

Place.	Population in 1890.	Depth.	Water bed.	Cover.	Waterworks.	
					Cost.[a]	System.
		Feet.				
Shelbyville	3,162	30- 50	Sand	Mainly till		Not from drift wells.
Sidney	581	30- 70	(?)	do		None.
Staunton	2,209	16- 40	Sand	Clay		Not from drift wells.
Steelville	401	18- 22	Clay	do		None.
Stewardson	617	20- 40	(?)	"Joint clay" (till ?)		Do.
Sullivan	1,468	W. W. 100-125	(?)	Mainly till		Pump to elevated tank.
Sumner	1,037	15- 20	Sand and gravel	Clay		None.
Sycamore	2,087	30-100+ W. W. 65	do do	Variable Blue clay	$60,000 Ex. 1,500	Pump to standpipe and direct pressure.
Toledo	676	10- 60	do	Mainly till		None.
Tuscola	1,897	174	Gravel	do	(?)	Pump to standpipe.
Upper Alton[b]	1,294	30- 50	Sandy clay	Loess and sandy clay		Under construction.
Urbana	3,511	10-200	Sand and gravel	Mainly till	175,000	See Champaign.
Vermont[b]	1,158	25- 35	(?)	do		None.
Virginia[b]	1,602	25- 50	Sand and gravel	do		Do.
Washington	2,301	25- 70	Quicksand	Blue till	15,000 Ex. 1,470	Morgan pumps.
Watseka	2,017	100-150	Sand and gravel	Mainly till	(?)	Pump to standpipe.
Waverly[b]	1,337	20- 50	(?)	Blue till		None.
Winchester[b]	1,542	20- 30	(?)	(?)		Do.
Winnetka	1,079	20- 50	(?)	Yellow and blue clay		Not from drift wells.
Wenona	1,053	16- 60	Sand	Mainly till		Under construction.
Whitehall[b]	1,961	25- 50	Gravel	Blue till		None.
Woodstock	1,683	20- 60	Sand and gravel	Mainly till		Not from drift wells.
Wyoming	1,116	22- 50	Gravel	Loess and till		None.

[a] "Ex." in this column means running expenses per annum.

[b] Occasional wells are in the rock.

In many instances the supply of water from the drift beds far exceeds the demands of a city, and there is no need to look to any other source for a supply. Where small wells are inadequate to supply a city it has been found of advantage to excavate a large well for a reservoir, from the bottom of which several small wells are bored into the main water bed. The rise of water is usually such as to cause it to enter the reservoir. In the following table the strength and head of some of the most important drift wells are shown:

Strength and head of certain drift wells.

Locality and owner.	Depth.	Head below surface.	Amount available per day.
	Feet.	*Feet.*	*Gallons.*
Beardstown waterworks	70	20	Unlimited.
Bement waterworks	155	25	100,000
Bloomington waterworks	65	25	500,000
Champaign waterworks	160	(?)	950,000+
Clinton waterworks	110	20	100,000+
Decatur private wells	100	20	(?)
Delavan waterworks	160	90	Unlimited.
Dwight waterworks	135	5	75,000+
Elpaso waterworks	105	40	Unlimited.
Eureka waterworks	105	60	Unlimited.
Galesburg waterworks	80	30	650,000
Gibson City waterworks	55	20	Unlimited.
Havana waterworks	74	25	(?)
Hoopstown private wells	80	20	150,000+
Keithsburg waterworks	50	25	Unlimited.
Leroy waterworks	110	50	Unlimited.
Macon waterworks	120	60	Unlimited.
Marengo waterworks	80	18	Unlimited.
Maroa waterworks	100	60	Unlimited.
Mattoon waterworks	70	(?)	(?)
Monticello waterworks	212	25	(?)
Paris waterworks	60	20	(?)
Paxton waterworks	150	50	Unlimited.
Pekin waterworks	80	42	3,000,000+
Peoria waterworks	50	10	8,000,000+
Rantoul waterworks	80	40	(?)
Sandwich waterworks	110	28	(?)
Sullivan waterworks	100	40	(?)
Washington waterworks	67	42	70,000+

SHALLOW WELLS IN ROCK.

A few villages obtain water from shallow wells in rock. This source of supply seems to be less reliable than that of wells in the drift. In the list of villages here given several having a population of 1,500 to 2,000 or more have not yet constructed waterworks, and the delay is largely due to insufficiency of water from shallow wells. Only two villages in this list obtain a supply for waterworks from shallow wells, viz, Earlville and Wheaton. The contrast in this respect with wells obtaining water from drift is striking, there being a large number of the latter which have a waterworks system.

Cities and villages using shallow wells in rock.

Place.	Population in 1890.	Depth. *a*	Water stratum.	Drift cover.	Rock cover.	Rise of water.
		Feet.				
Abingdon	1,321	20- 30	Coal Measures?	(?)	(?)	(?)
Anna	2,295	20- 60 40	Limestone	Drift, 6-8	Rock, 12-50	6-7 feet.
Ashley	1,035	8- 40 28- 35	Sandy shale	Drift, 8-15	Rock, 0-25	Slight.
Chenoa	1,226	10-150 100-150	Coal Measures	(?)	(?)	10 feet from surface.
Columbia	1,267	20- 45	Limestone	Clay, 10-20	Shale, etc., 10-20	(?)
Dallas City	747	10-150	....do	Drift, 2-4	Limestone, 8-110	Various.
Equality	622	30- 40	Sandy shale	Clay	Clay shale	(?)
Fairfield	1,881	15- 20 50- 70	....do	Clay, 4-6	Shale, 10-20	12 feet from surface.
Freeport *b*	10,189	10- 90	Galena limestone	Drift, 6-30	Limestone	(?)
Fulton	2,099	60- 70	Limestone	Loess, 12	....do	(?)
Golconda	1,174	30- 40	....do	None	Limestone and sandstone	(?)
Hutsonville	582	9- 30	Sandstone	(?)	(?)	3-4 feet.
Kinmundy	1,045	10- 30	....do	Drift, 12±	Shale, etc	5-20 feet.
Knoxville	1,728	20- 40	Coal Measures	Drift, 10±	Shale	10-20 feet.
Lawrenceville	865	12- 60 60	Sandstone	Drift, 12	Sandstone, etc	20 feet from surface.
Lebanon	1,636	150-200	(?)	(?)	Coal Measures	8-12 feet.
Marshall	1,900	12- 45	Sandstone	Drift, 10-20	Sandstone, etc	(?)
Martinsville *b*	779	70- 80	(?)	Drift ?	(?)	(?)
McLeansboro	1,355	10-160 10- 12	Sandstone	Clay, 6 or 8	Shale, 4	(?)
Millstadt	1,186	25- 40	Limestone	Loess, 10	Limestone	6-12 feet.
Momence	1,635	12- 80 30	....do	(?)	....do	16-18 feet from surface.

Morrison *b*	2,088	35- 80 75	do	Drift, 8-20	do	(?)
Mount Carmel *b*	3,376	15- 40	Limestone ?	Drift, 12-15	Sandstone, etc	(?)
Nashville	2,084	14- 45	Sandstone	Drift clay, 10	Shale, sandstone, etc.	10 feet.
Pecatonica	1,059	8-125	Limestone	(?)	Limestone	40 feet.
Quincy *b*	31,494	90-200	do	(?)	do	60 feet from surface.
Red Bud	1,176	20- 80 40	*Limestone or sandstone*	Drift, 8-12	*Limestone shale*	(?)
Robinson	1,387	12- 25	Sandstone	(?)	Shale sandstone, etc	3-5 feet.
Rochelle *b*	1,789	20- 60 30- 40	Sandstone ?	(?)	Limestone	(?)
Shannon	591	(?)	Limestone	Till, 10-15	do	(?)
St. Francisville	432	15	(?)	(?)	(?)	4-6 feet.
Vienna	828	25- 60 50	Limestone	(?)	Limestone	20-30 feet.
Virden	1,610	15- 50 15- 25	Sandstone, etc	Drift, 10-20	Shale, etc.	20 feet from surface.
Warren	1,172	50-125 80	Limestone	Clay, 15	Limestone	35-50 feet.
Waterloo	1,860	20- 80	do	Drift, 10-30	Limestone, etc	(?)

a Where there are two sets of numbers in this column the lower ones indicate the main water horizon.
b Only a small portion of the water supply is from this class of wells.

DEEP WELLS IN ROCK.

About 75 towns in Illinois obtain a portion of their water from wells which have been carried several hundred feet into the rock strata. With a few exceptions, the water is made use of in dwellings as well as for manufacturing purposes, and seldom has a disagreeable taste. It is probable that in many wells the water has been freshened and rendered more agreeable by the addition of water from the glacial deposits, for there are few wells in which the casing entirely shuts out such water. The degree of salinity of several water horizons apparently increases in passing from north to south, as is shown in the discussion of artesian wells. In consequence of this salinity, the use of such water is mainly in the north end of the State. There are very few wells in the eastern part of the State to the south of the Kankakee and Illinois rivers. In the western part, however, artesian wells are scattered widely and are in but few instances unfit for domestic use.

Cities using water from deep wells.

City.	Population in 1890.	Depth.	Diameter.	Capacity per minute.	Head from surface.	Waterworks.	
						Cost. *a*	System.
		Feet.	*Inches.*	*Gallons.*	*Feet.*		
Aledo	1,601	3,115	(?)	...	— 75	Ex. $1,200	Pump to standpipe.
Amboy	2,257	2,000	...	...	3	...	Incomplete.
Arlington Heights	1,424	...	...	...	...	...	
Aurora, No. 1	19,688	1,388	...	350	...	320,000 Ex. 10,733	Pump to standpipe.
Aurora, No. 2		2,270	...	...	60	...	
Aurora, No. 3		2,255	...	...	60	...	
Austin	4,051	1,205	...	...	...	...	
Barry	1,354	2,510	6	100+	—135	13,000 Ex. 550	Tank; pumped from well.
Belvidere	3,867	1,932	8-6	200	— 6	...	Pump to standpipe.
Canton, No. 1	5,604	2,500	4	125	— 30	...	Pump to standpipe, and direct.
Canton, No. 2		1,646	6	260	+ 14		
Carthage, No. 1	1,654	1,700	5-3	(?)	— 16	10,000	Pump to elevated tank.
Carthage, No. 2		1,000	8	...	— 20	...	
Collinsville	3,498	573	...	17	—120	21,500 Ex. 1,000	Pump to standpipe.
Dekalb, No. 4	2,579	890	6	300—	— 65	30,000 Ex. 1,470	Pump to standpipe, and direct.
Dixon	5,161	1,640	...	525	8	100,000	Do.
		1,730	...	...	...	...	
		1,810	...	...	...	...	
Earlville	1,058	150	...	...	— 15	...	
East Dubuque	1,069	940	5	420	95	...	
Elgin (hospital)	...	2,026	6	(?)	— 4	...	
Fairbury	2,324	2,002	...	...	— 60	25,000 Ex. 1,200	Fairbanks, Morse & Co.
Forreston	1,118	300	8	...	— 25	8,000 Ex. 400	Pump to water tower.

a "Ex." in this column means running expenses per annum.

Cities using water from deep wells—Continued.

City.	Population in 1890.	Depth.	Diameter.	Capacity per minute.	Head from surface.	Waterworks.	
						Cost. *a*	System.
		Feet.	*Inches.*	*Gallons.*	*Feet.*		
Fulton	2,099	1,246	(?)	300	60 20	$11,000 Ex. 1,500	Elevated underground reservoir; pump from well.
Galena	5,635	1,509	8	166	85	(?)	Pump direct from well.
Geneseo court-house.	3,182	2,250	6	200	25	(?)	(?)
Geneva	1,692	2,500	(?)	(?)	(?)	....	
Hamilton Sanitarium.	1,301	680	(?)	(?)	63	....	
Harvard (railroad well).	....	900	7	100+	— 41	9,000	Pump to tank.
Harvey	(?)	1,300	(?)	250	— 10	100,000 Ex. 5,800	Pump to standpipe, and direct pressure.
Hennepin	574	800	4	80	50	....	
Henry	1,512	1,355	3½	32	(?)	....	
Highland Park	2,163	2,200	5	150	0	60,000	Dean pumps.
Hinsdale	1,584	864	(?)	(?)	(?)	(?)	Pump to standpipe.
Hoopeston	1,911	350	8	175	— 20	50,000 Ex. 2,500	Pump to reservoir, then to standpipe.
Ipava	667	1,570	4	60	— 16	3,100 Ex. 365	Pump to standpipe.
Jacksonville	12,935	2,343	6	30	— 15	200,000	Pump to reservoir.
Jacksonville, No. 2		3,028	5⅝	500	— 30	Ex. 7,000	
Jerseyville	3,207	2,003	6–3	55	—100	35,000 Ex. 1,800	Gravity and pump direct.
Joliet	23,264	1,200 1,700	(?)	570	— 16	(?) Ex. 13,500	Holley system.
Kewanee	4,969	1,480	6	125	—150	(?) Ex. 4,000	Direct pressure.
Kewanee, No. 2		1,050	4	75	—150	....	
Kewanee, No. 3		1,050	4	50	—150	....	
Lagrange	2,314	2,014	(?)	(?)	(?)	(?)	Pump to standpipe.
Lasalle	9,855	502	6	200	(?)	(?)	Direct pressure.
Lemont	6,000	1,366	(?)	(?)	60	(?)	(?)
Lockport	2,449	(?)	(?)	(?)	(?)	(?)	(?)
Macomb	4,052	1,350	(?)	(?)	— 55	30,000 Ex. 1,500	Pump to standpipe, and direct pressure.
Marseilles (275 wells).	2,210	100 150 200	2±	6 1½	5	....	Private wells.
Mendota	3,542	400	(?)	70	— 40	50,000 Ex. 3,280	Direct pressure.
Minonk	2,316	1,755	6	100	—150	20,000	Pump to standpipe.
Monmouth	5,936	1,400	6–4	210	— 60	(?) Ex. 4,000	Holley system.
Morgan Park	1,027	1,046	(?)	(?)	— 46	(?)	(?)
Morris	3,653	600	(?)	16	12	32,000 Ex. 1,500	Holley system.
Mount Carroll	1,836	2,502	5	....	— 20	(?)	Pump to standpipe.

a "Ex." in this column means running expenses per annum.

Cities using water from deep wells—Continued.

City.	Population in 1890.	Depth.	Diameter.	Capacity per minute.	Head from surface.	Waterworks.	
						Cost. *a*	System.
		Feet.	*Inches.*	*Gallons.*	*Feet.*		
Oakpark	4,771	1,568	6½	500	— 12	$400,000	Air compressor and Worthington pumps.
Oakpark, No. 2		2,180	6	175	— 12	....	
Ottawa (200 wells)	9,985	400 ±	4–6	....	....	....	Private wells.
Parkridge	987	1,500	6 3½	(?)	— 8	(?)	(?)
Polo	1,728	2,100	(?)	(?)	— 70	18,000 Ex. 700	Morgan pumps.
Princeton	3,396	2,095	4⅝	320	— 72	95,000	Pump to standpipe.
Riverside	1,000	1.300	3½	1,000?	(?)	(?)	Air compressor; pump to standpipe.
Riverside, No. 2		2,200	(?)	....	(?)	....	
Rockford	23,584	400	6	(?)	8	538,121 Ex. 17,452	Direct pressure.
Rockford, No. 2		1,300	6	250	8	....	
Rockford, No. 3		2,000	6	220	8	....	
Rushville	2,031	2,500	(?)	(?)	(?)	20,000 Ex. 720	Pump to standpipe.
Savanna	3,097	1,430	....	500	83	....	Pump to reservoir on hill.
Seneca	1,190	350	(?)	(?)	(?)	....	None.
Seneca, No. 2		680	4	(?)	22	....	
Sparta	1,979	480	(?)	(?)	— 80	....	Do.
Steeleville	401	312	2	2	+?	....	Do.
Sterling	5,824	1,450	8–6	900	+?	50,000 Ex. 3,000	Pump to standpipe.
Utica	1,094	325	(?)	140	50	(?)	Hydrants on wells.
Warsaw	2,721	860	6	200	100	....	Natural pressure.
Washington Heights	2,283	1,308	(?)	(?)	(?)	(?)	(?)
Wenona	1,053	1,854	(?)	100	—125	....	Under construction
Wheaton	1,622	178	10	300	— 20	33,600	Pump to standpipe.
Wilmington	1,576	635	4½	(?)	46	10,000	Direct pressure.
Winnetka	1,079	1,900	(?)	(?)	(?)	80,000	Worthington pumps to water tower.
Woodstock	1,683	1,014	(?)	500	(?)	30,000	Pump to standpipe.

a "Ex." in this column means running expenses per annum.

CHAPTER VII.

WATER SUPPLIES FOR RURAL DISTRICTS.

GROUND-WATER WELLS.

This term covers a class of shallow wells which derive much of their water from the ground immediately surrounding them, and which are directly dependent upon its saturation. These wells are to be distinguished from wells that derive their supply from a distance, whether those wells be deep or shallow. Ordinarily, they are called surface or seep wells, and the local source of supply is thus recognized.

In ground-water wells the level of the water is about the same as in the bordering formations, and rises and falls with the fluctuations of the ground water, being near the top of the well in wet seasons, when the ground is saturated, but at a considerably lower depth in seasons of drought. The fluctuation of such wells has been carefully studied by Prof. F. H. King, of the Wisconsin Agricultural Experiment Station, at Madison, and the results appear as a bulletin of the Weather Bureau.[1] Professor King finds that the fluctuations are very complex. There are not only high and low stages due to the amount of rainfall, but changes due to soil temperature and to barometric pressure, and even slight oscillations caused by the passage of a heavily loaded railway train. The influence of rainfall is, however, the only one of the several modifying influences which greatly affects the value of a well, for the changes effected by soil temperature, barometric pressure, etc., amount to but few inches.

The several deposits that form the immediate surface of the State include bowlder clay or till, loess, compact silts, sand, gravel, and the various rock formations with their several varieties of limestone, shale, and sandstone. The rock formations are throughout much of the State so deeply buried beneath the drift that they are not reached by ground-water wells. In the portions of the State where the rock formations are near the surface they are usually mantled by one or more of a variety of deposits, including the several classes of drift and silts of Glacial age, as well as residuary clays. But it is often the case that this mantle is too thin to hold sufficient water to supply a well, and then the rocks are drawn upon. If a well from the rock derives its supply by percolation from the soil on its immediate borders, it is as

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[1] Fluctuations in the level and rate of movement of ground water, by Franklin H. King: U. S. Department of Agriculture, Weather Bureau Bull. No. 5, Washington, D. C., 1892, 75 pp.

truly a ground-water well as one which obtains its supply without entering rock. On low ground, shallow wells in the rock, and also wells in the drift, may be fed from a distance, in which case they are not of this class. The ground water often saturates a rock formation in a wet season nearly or quite to the surface, and in such case the well, as in drift deposits, may become lowered to a depth of several feet in seasons of drought. The ground-water wells are therefore not limited to any one class of formations, but, on the contrary, they may be found in nearly every formation represented in the State.

As the surface formations vary greatly in their capacity to furnish water to wells, the strength of wells may be expected to vary also. Wells in porous formations, as gravel or sand, or in sandstone, are, as a rule, far stronger than wells in compact deposits, such as bowlder clay, shale, or limestone.

The bowlder clay shows, perhaps, greater variations in texture than any other of the formations mentioned. It ranges from a close-textured and oily clay without joints to a very coarse-textured deposit with a matrix nearly as pervious as water-bedded sand. In places, also, it is broken by frequent joints, through which water finds passage. This is more conspicuously the case in the older drift than in the newer. Such joints are usually filled with coarse material carried by the percolating streams, and thus have the appearance of veins of sand or fine gravel. Wells of considerable strength are found if water-bearing joints or veins are struck, while neighboring wells which miss such joints may be weak. Bowlder clay is also often intimately associated with deposits of sand or gravel. When such deposits are of limited extent, and completely inclosed by bowlder clay, they are of value only in extending the reservoir beyond the limits of the well; but when of great extent they usually furnish strong and lasting wells. The value of a well may also depend largely upon its position. If on the brow of a bluff or the terrace of a stream, it may be subject to greater fluctuations than a well in similar formations on the uplands. Wells made in the sand or other porous deposits of a river terrace will often fluctuate as greatly as the stream, even though distant several miles from it. Conspicuous examples occur on the Wabash, Illinois, and Mississippi terraces. In general it may be said that fluctuation in the level of ground-water wells is proportioned to the nearness to a drainage line. But there are frequent exceptions, which occasion remark by the residents, and which may usually be attributed to structural conditions that prevent escape to the valleys. The valley naturally exhausts first the water contained in the formations on its immediate borders, and then lowers the water level at greater distance. Just so a well, as indicated by Professor King, drains the strata for but a short distance in wet seasons, but greatly extends its drainage area in seasons of drought.

In Illinois bowlder clay is by far the most important source of supply for ground-water wells. It is only in the portion of the State lying north of the Kankakee and the west-flowing portion of the Illinois that such wells are largely derived from sand and gravel, and only in a few counties in the southeastern part of the State are they derived to any great extent from sandstone and sandy shales. Limestones supply only small areas in northeastern Illinois, a limited district in the northwestern corner, and a narrow strip on the western border and in the southern part of the State; while Tertiary deposits of sand and gravel supply the extreme southern end of the State.

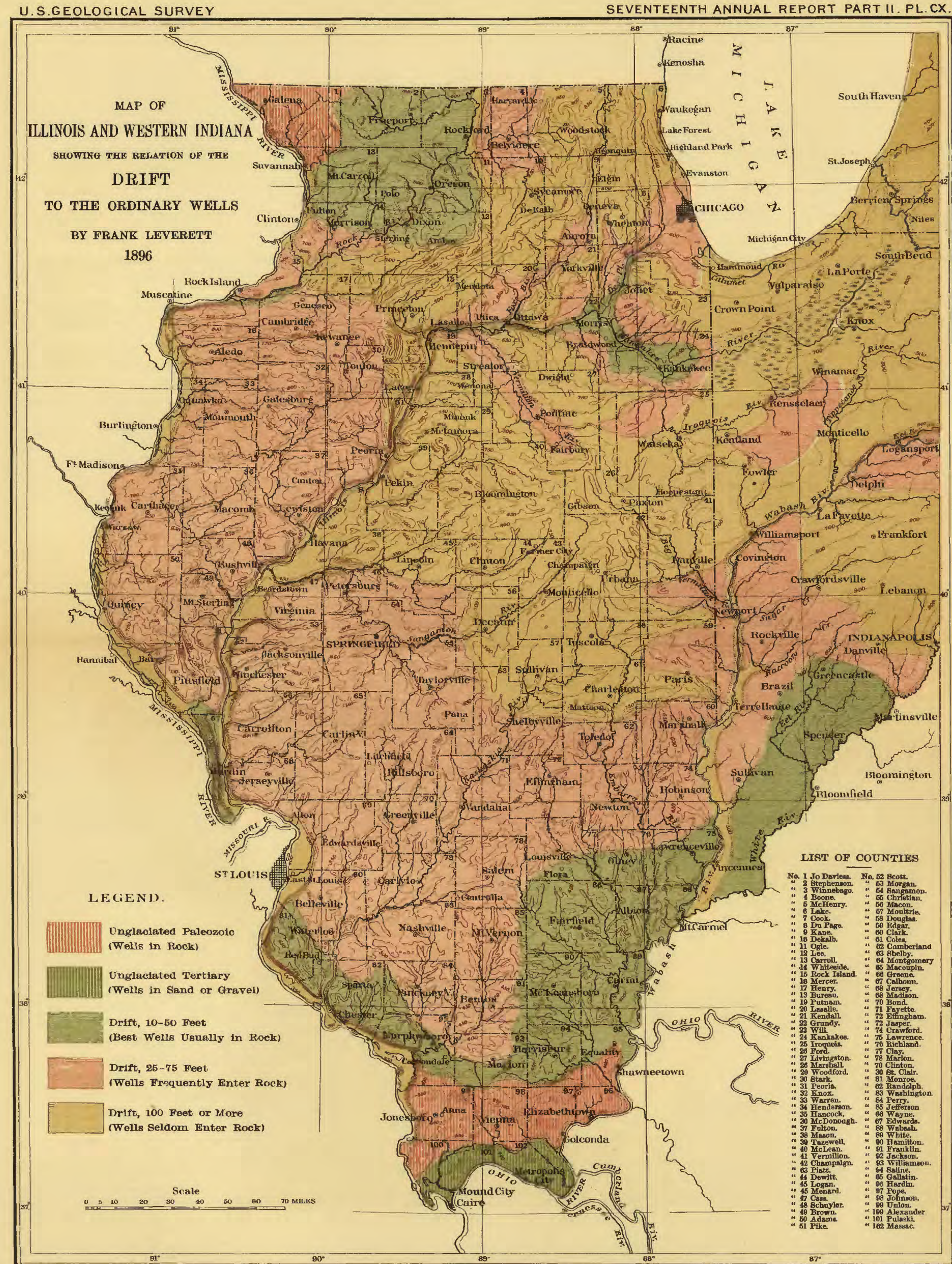
On the accompanying map (Pl. CX) the extent of these districts may be seen. The elevated driftless tracts of the northwest corner and the southern end of the State obtain wells almost entirely from the rock, the only exceptions being along valleys, where they are obtained from alluvium. Occasional weak wells are obtained, however, at the base of the loess, which mantles much of these districts to a depth of several feet. In these elevated districts, ground-water wells are not in such general use as in the remainder of the State. Cisterns are relied upon in southern Illinois, while wells 50 to 150 feet or more in depth, which are independent of the percolations of the immediate border, are numerous in northwestern Illinois. In each district, however, there are quite extensive areas where shallow wells may be obtained.

In the sandstone district of southeastern Illinois wells frequently enter rock at a depth of 8 to 10 feet and obtain a water supply at depths of but 20 to 30 feet. The only notable exception is on the narrow ridges or mounds of rock, where they are deeper. In the limestone district bordering the Kankakee and Des Plaines and extending into southern Kendall County water is usually obtained at 25 to 40 feet. In the region of thin drift in northwestern Illinois the majority of ground-water wells obtain their supply without entering the rock, at depths of 15 to 30 feet, but they have frequently to be supplemented by cisterns.

There are very extensive districts in western and southern Illinois (indicated on the map, Pl. CX) where wells for household use are mainly in the drift, but the stock wells are frequently sunk into the rock. Wells of sufficient strength for household use, with a capacity of 1 to 5 barrels per day, may usually be obtained throughout these extensive districts at the convenient depths of 15 to 25 feet. The majority have probably a daily capacity of not more than 2 barrels, and many will become dry in seasons of extreme drought. It is very seldom, however, that the weakness of the wells causes serious inconvenience, as in almost every village a few wells may be found which will yield enough to supply several families. In farming districts where it is impracticable to puncture the earth with numerous borings and thus obtain the best shallow wells, it becomes necessary in many cases to sink deep wells. Such wells are usually put down to sufficient depth to derive their supply from wide areas, and are thus removed from the class of wells under discussion.

With the exception of several small areas (represented on the map, Pl. CX) in which the drift is so thin that a part of the wells must be sunk into the rock, the northeastern part of Illinois, including, perhaps, one-third of the State, has a coating of drift so thick that it is a rare occurrence for a well to penetrate it. The average thickness of the drift is estimated to be not less than 100 feet, while in places it exceeds 300 feet. If ground-water wells prove too weak, the wells are sunk, not to rock, but to deep-lying and somewhat extensive water-bearing beds, which are there inclosed in the drift. This region is variable in its advantages for ground-water wells. In the northern part, from the Kankakee and Illinois rivers northward, there is usually an adequate supply at convenient depths, because of the presence of sand and gravel in large amount. In the district south and east from the Illinois the ground-water wells are often weak, because of the very compact character of the upper part of the bowlder clay. In this district, however, the bowlder clay is quite extensively underlain by beds of sand and gravel, which furnish strong wells at moderate depths—50 to 150 feet.

The effect of the droughts of 1894 and 1895 upon ground-water wells was more severe than that of any other drought since the settlement of the State. In many localities where such wells before yielded a sufficient supply a large number became entirely dry because the available ground water was exhausted. The depth to which exhaustion extended varied greatly. In some localities it affected only wells less than 20 feet in depth, while in others it included wells 30 feet or more in depth. The writer's studies in the season of 1895 were mainly in southeastern Iowa, a district underlain by a compact bowlder clay broken by frequent joints and differing but little from that of western Illinois. Wells 30 feet in depth were affected by the drought, and in consequence a large number have been extended to a depth of 50 feet or more. In its deeper portion the clay has been found to yield water in about as great amount as is yielded by the upper portion in ordinary seasons. In southeastern Iowa many shallow wells are made by farmers at convenient places on the farm for watering stock. Such wells are often not in use for long periods because of a shifting of pasture fields to other parts of the farms. When the drought came on and the wells in use gave out, the farmers turned to such wells, expecting to find a supply of water, but in a great many instances the wells were found to be empty. It is therefore evident that the ground water which usually feeds such wells had been completely exhausted, at least to the depth of their bottoms. To obtain wells in new places it is necessary to sink to greater depths than formerly. What was observed by the writer in southeastern Iowa appears from correspondence to be generally true over till-covered areas in the entire district affected by the drought, which includes most of the central portion of the Mississippi Basin. Observations were made by the writer at many freshly dug wells in southeastern Iowa to determine to what depth the subsoil had become dry. The subsoil is a compact loess, such as requires tile


MAP OF
ILLINOIS AND WESTERN INDIANA
SHOWING THE RELATION OF THE
DRIFT
TO THE ORDINARY WELLS
BY FRANK LEVERETT
1896
LEGEND.
Unglaciated Paleozoic (Wells in Rock)
Unglaciated Tertiary (Wells in Sand or Gravel)
Drift, 10-50 Feet (Best Wells Usually in Rock)
Drift, 25-75 Feet (Wells Frequently Enter Rock)
Drift, 100 Feet or More (Wells Seldom Enter Rock)
Scale
0 5 10 20 30 40 50 60 70 MILES
LIST OF COUNTIES
No. 1 Jo Daviess.
" 2 Stephenson.
" 3 Winnebago.
" 4 Boone.
" 5 McHenry.
" 6 Lake.
" 7 Cook.
" 8 Du Page.
" 9 Kane.
" 10 Dekalb.
" 11 Ogle.
" 12 Lee.
" 13 Carroll.
" 14 Whiteside.
" 15 Rock Island.
" 16 Mercer.
" 17 Henry.
" 18 Bureau.
" 19 Putnam.
" 20 Lasalle.
" 21 Kendall.
" 22 Grundy.
" 23 Will.
" 24 Kankakee.
" 25 Iroquois.
" 26 Ford.
" 27 Livingston.
" 28 Marshall.
" 29 Woodford.
" 30 Stark.
" 31 Peoria.
" 32 Knox.
" 33 Warren.
" 34 Henderson.
" 35 Hancock.
" 36 McDonough.
" 37 Fulton.
" 38 Mason.
" 39 Tazewell.
" 40 McLean.
" 41 Vermilion.
" 42 Champaign.
" 43 Piatt.
" 44 Dewitt.
" 45 Logan.
" 46 Menard.
" 47 Cass.
" 48 Schuyler.
" 49 Brown.
" 50 Adams.
" 51 Pike.
No. 52 Scott.
" 53 Morgan.
" 54 Sangamon.
" 55 Christian.
" 56 Macon.
" 57 Moultrie.
" 58 Douglas.
" 59 Edgar.
" 60 Clark.
" 61 Coles.
" 62 Cumberland
" 63 Shelby.
" 64 Montgomery
" 65 Macoupin.
" 66 Greene.
" 67 Calhoun.
" 68 Jersey.
" 69 Madison.
" 70 Bond.
" 71 Fayette.
" 72 Effingham.
" 73 Jasper.
" 74 Crawford.
" 75 Lawrence.
" 76 Richland.
" 77 Clay.
" 78 Marion.
" 79 Clinton.
" 80 St. Clair.
" 81 Monroe.
" 82 Randolph.
" 83 Washington.
" 84 Perry.
" 85 Jefferson.
" 86 Wayne.
" 87 Edwards.
" 88 Wabash.
" 89 White.
" 90 Hamilton.
" 91 Franklin.
" 92 Jackson.
" 93 Williamson.
" 94 Saline.
" 95 Gallatin.
" 96 Hardin.
" 97 Pope.
" 98 Johnson.
" 99 Union.
" 100 Alexander
" 101 Pulaski.
" 102 Massac.
LAKE MICHIGAN
CHICAGO
ST LOUIS
SPRINGFIELD
INDIANAPOLIS
JULIUS BIEN & CO N.Y.

draining. It was found generally to be dry to a depth of but 3 to 4 feet, though the upper 10 feet were seldom sufficiently moist to be easily spaded. As the loess is but 6 to 8 feet thick, the upper part of the underlying till is affected. The heavy rains which fell in December, 1895, are reported to have moistened the ground only to a depth of 4 to 6 feet. At the present writing (April, 1896) they have not had an appreciable effect upon the wells.

It is quite generally believed by the old settlers of Illinois and bordering States that the shallow wells are becoming permanently lower, but in the absence of statistics only the probable influence of settlement upon such wells can be considered. Much of Illinois, covered as it was with a heavy and tangled mass of prairie grass, had originally a poor surface drainage. In consequence the ground became completely saturated by the heavy rains. The effect of settlement has been to afford better surface drainage by opening ditches and removing obstructions, and thus to lessen the amount of saturation. Cultivation of fields, leading as it usually does to a more rapid escape of water over the surface, also tends to lessen the degree of saturation. A somewhat reduced supply to shallow wells and a more frequent failure of such wells than in the days of early settlement are therefore to be expected.

In Illinois the value of ground-water wells as a source of water supply is vastly greater than that of all other wells combined. There are probably 20 such wells for every deep well in the State, there being on an average not fewer than 10 wells for every mile of the 56,000 square miles of land surface. The value of the wells is not so much in the quantity of water furnished as in its ready accessibility. The wells for household use probably yield an average of but 2 barrels per day, and these comprise fully 75 per cent of the wells, or not fewer than 420,000. The stock wells of this class yield on an average perhaps 5 barrels per day. The total supply from this source is therefore about 840,000 barrels for household consumption and 700,000 barrels for stock, or about 1,500,000 barrels per day. About one-half the population of the State is thus supplied with water for cooking and drinking, the other half being supplied mainly from Lake Michigan and from the streams; deep wells, as is indicated further on, furnishing the supply for but a small part of the population.

The dependence upon ground-water wells being so great, it becomes a matter of much importance to insure favorable sanitary conditions. In this respect the people of Illinois are exceedingly careless. It is estimated that at least one-half the wells are so situated as to invite pollution. Many of them are placed at the side of the house where slops are emptied, and it is certain that a considerable percentage of such wells receive the slops without much filtering. In not a few cases the wells are so situated as to be within the range of drainage from privies. Nearly every farm furnishes an example of a well situated in the midst of the barnyard, where manure heaps readily drain into it, and these wells are used by the men when about the work of the barn. In not a few instances the writer has found the pollution of such wells to be so great as to be detectable by the odor and the color of the water, and the farmer often observes this condition and is yet too careless to avoid using the water.

A circular letter sent out by the writer to the principal villages and cities of Illinois, Indiana, and Ohio contained the questions: "Are the shallow wells obtained below a bed of clay or impervious stratum of sufficient thickness to prevent contamination of the water from cesspools or other sources? What is the thickness and what the character of such overlying beds?" In at least 90 per cent of the replies the first question was answered in the affirmative, and yet in many cases the further statement is made that the impervious bed is but a few inches in thickness. From personal observation of the position of village wells in reference to cesspools the writer is convinced that the majority are liable to contamination from that source. It seems not at all remarkable, therefore, that typhoid fever so often becomes epidemic both in the villages and in the country districts of Illinois. In the country districts there is certainly abundant space for the proper distribution of privies, wells, and barnyards, and everywhere it is possible to greatly improve the relative position of privies and wells and to avoid throwing slops and refuse matter where a well will be apt to receive them.

DRIFT WELLS WITH WIDE OR REMOTE ABSORPTION AREAS.

In the wells just described the water supply is derived from the ground immediately surrounding the well mouth. In the class of wells now to be discussed the supply depends scarcely at all upon the ground around the well mouth. They are usually so deep that no water gains access to them from this source, though in some cases, as in valleys, they are shallow and are fed from the immediate borders as well as from a distance. Commonly their supply is derived from beds of gravel or sand which are interbedded with the sheets of till. They are supposed to be fed, like the water supplies found in the rock strata, from surface outcrops of the water-filled beds or through joints or other openings in the overlying drift sheet. Like artesian wells, they usually show a marked rise of water above the level at which water is struck, and in many cases they overflow. This class of wells is represented very widely in the State, and yet such wells are certain to be obtained in only a few localities, since the proper arrangement of drift beds for the concentration of water in underground sheets does not prevail widely.

The limits of districts where they may be found are not yet ascertained, and will be known only after a thorough testing by well borings. Perhaps the most extensive district in the State is found in Iroquois County, where, as shown below, flowing wells from the drift abound.

The water-bearing beds here appear to derive their supply from the bordering moraine and other elevated tracts on the south and west. Another large district is found on the plain lying east of the Marseilles moraine and bordering the head of the Illinois River. In that district there is usually a marked rise in the water when found in sand or gravel below till, and there are occasional flowing wells. The source of the water is thought to be in the bordering moraine. Another large district where wells rise nearly to the surface and occasionally overflow is found on the west side of Fox River from the Illinois River northward beyond the State line. In the southern part of this district the wells are located on a plain with elevated moraines on the west border, from which the water supply is probably derived. In the northern part of the district the wells which show a marked rise are found in the narrow plains and low tracts between the morainic belts. Still another extensive district characterized by occasional flowing wells and by a general rise in water found in sand or gravel beds lies along the east slope of the Valparaiso moraine in Lake, Cook, and Dupage counties. Here also the supply appears to be from the moraine.

The districts just mentioned are more uniformly favored with strong wells and with a marked rise of water than any other portions of the State. The drift beds of the moraines appear to dip toward and pass under the plains on their north and east borders, as is to be expected if we consider the method of drift deposition.

In many places in central and eastern Illinois where the drift is very thick, wells of this class are found, but the chances of striking strong wells are fewer, and the rise of water is less uniform and on the whole less pronounced than in the districts just mentioned. Notwithstanding these uncertainties, there are hundreds of successful wells. Several cities in that region have found abundant supplies of water from the drift beds, among which are Peoria, Bloomington, Lincoln, Champaign, Mattoon, and Paris, each of which has a population of several thousand. By reference to the list of towns which obtain water supplies from the drift many others may be added. Such wells are in great demand by stock raisers, and are therefore rapidly coming into use in rural districts.

In western Illinois the wells of this class are numerous, but there is even less certainty of finding a strong well than in central and eastern Illinois, for the drift contains on the whole a smaller proportion of sand and gravel and is a thinner deposit.

In southern Illinois, from the Shelbyville moraine southward, this class of wells is to be found only in a few localities of small extent. They usually occur along the line of pre-glacial valleys, where the drift is exceptionally thick, and where it shows a tendency toward a sandy constitution.

Wells of this class are of inestimable value to the many villages and cities where they may be obtained and to the stock raisers in the rural districts. The quality of water is the best to be found at any horizon, for there is freedom from the contamination to which surface water and water from shallow wells is liable. There are also very few wells in which the mineral ingredients are at all objectionable. These wells should displace the ground-water wells wherever practicable.

The average depth of these wells probably does not exceed 100 feet, but even where it is necessary to sink a well to a depth of 200 or 300 feet the excellent quality and large quantity of water usually justify the outlay. To wells of this class it is customary to attach a windmill, and thus dispense with the labor of drawing water by hand. The wells in the rural districts are ordinarily not more than 4 inches in diameter. Unless they will stand a test of 4 gallons per minute they are considered too weak to justify the erection of a windmill. But there is scarcely a township of the district included by the Shelbyville moraine, except where drift deposits are thin, which does not already show several of these strong wells with windmill attached; and in the most favored districts, as outlined above, there is scarcely a square mile without its strong well and windmill pump. In western Illinois the number of strong wells is nearly as great as in the district included by that moraine, but there is a large percentage which have been extended into the rock.

FLOWING WELLS FROM THE DRIFT.

GENERAL STATEMENT.

In a few small areas the drift has furnished an overflow of water from wells. These areas are usually on the slopes of moraines or along valleys in which there is a thick filling of drift. The water appears to be derived from the moraines, or, in the case of valley wells, from the higher ground bordering the valley. This class of wells differs from the class just considered only in the matter of overflowing. The rise of water is in many cases no greater than in wells which do not overflow. The overflow is due to the low altitude of the surface rather than to exceptionally great rise of water.

The principal districts with this class of wells are shown on the artesian-well map (Pl. CXIII). The largest district characterized by this class of flowing wells is found in a drift basin in Iroquois County and the border portions of adjacent counties in eastern Illinois. It comprises an area of at least 500 square miles. A small district is found in northern Vermilion County, near the Middle Fork of Vermilion River. There are also small districts near Plattville, in Kendall County; near Earlville, in northern Lasalle County, and adjacent portions of Lee and Dekalb counties; near Sycamore, in northern Dekalb County; near Palatine, in northern Cook County, and along Salt Creek Valley, in northern Cook and eastern Dupage counties. A few flowing wells are found also along the North Fork of Chicago River, in northern Cook County and southern Lake County. Flowing wells are also common in the low-lying tracts among moraines of Lake, McHenry, and Kane counties. The combined area of all these small districts will probably not greatly exceed that of the Iroquois district (500 square miles). Flowing wells are frequently obtained on the Sangamon and its tributaries, especially those which head within the limits of the Shelbyville moraine, among which may be mentioned Vermilion, Mackinaw, Kaskaskia, and Embarras rivers. These valleys are not, however, generally favorable localities for such wells.

It will be observed that all the flowing-well districts above mentioned lie within the limits of the Shelbyville moraine, and that the scattering wells are mainly to be found within the same limits. In the outlying portion of the State these wells are confined to a few valleys, and are seldom in areas of sufficient size to merit mention.

FLOWING-WELL DISTRICT OF IROQUOIS AND ADJOINING COUNTIES.

The northern boundary of this district, from Watseka, in Iroquois County, to Piper City, in Ford County, lies parallel to and about 3 miles distant from the north side of the Toledo, Peoria and Western Railway. On the west and south the boundary lies near the border between the plain and the morainic tract southwest of it. It passes from Piper City through Thawville and Bulkley to the extreme southern part of Iroquois County, thence up Fountain Creek Valley a short distance into Vermilion County, and thence northeast to within 2 miles of Wellington, Iroquois County. The eastern boundary has a somewhat sinuous course, following approximately the line of the Chicago and Eastern Illinois Railroad from the vicinity of Wellington to Watseka.

Aside from the main belt, there is a narrow belt along the Vermilion marsh north of Piper City, where a few flowing wells have been obtained. There is also a narrow flowing-well district along the Iroquois River from Sugar Island, in northern Iroquois County, Ill., up to Rensselaer, Ind. Similar narrow belts extend for several miles up the tributaries of the Iroquois in northern Iroquois County. In these narrow belts along the Iroquois and its tributaries the wells, as a rule, overflow at the surface only when obtained on the low bottom, which is subject to inundation when the streams are high. It is probable that wells along the upper portion of the Iroquois derive water from a source independent of that which supplies the main district.

In the midst of the main district, leading from Milford westward past Onarga, there is an undulatory belt having a width of 3 miles or more where the water fails to reach the surface by a few feet.

In the main well district two serious elements of uncertainty occur: First, the uncertainty of striking a water-bearing bed at any given depth, for the beds are usually thin and subject to interruptions; second, the danger of the surface elevation being too great, since where the flows are successful the water rises to a height of but a few feet above the surface.

The first element of uncertainty has proved in many cases to be of little consequence, since the artesian water is found at not less than three different levels, and it is rare that all three water-bearing beds are absent in any one boring. It is often the case, however, that only very weak flows are obtained.

The second element of uncertainty necessarily affects much of the district, since a rise of ground of but 5 to 10 feet often makes a flow impossible, even in places where veins are struck from which water rises in great volume, there being insufficient head to reach the surface. The uncertainty is very great all along the borders of the main district and in quite an extensive tract south and east of Gilman.

Outside of the territory described above as the flowing-well district there is over a considerable tract a rise of water nearly to the surface. In the sand-covered belt north of the Iroquois River water rises to within 10 to 15 feet of the surface, except on high points near the border of the Erie-Saginaw moraine. On the opposite side of the Iroquois, between the flowing-well district and the Marseilles moraine, water rises to within 25 feet of the surface on the higher portions of the plain and almost flows in low ground near the creeks. East from the flowing-well district as far as the Indiana line there is considerable rise of water in deep wells.

The only member of the drift series within this flowing-well district which possesses anything like uniformity of distribution and thickness is a sheet of slightly pebbly, compact blue clay, which immediately underlies the yellow clay subsoil and overlies the first water bed from which flows are obtained. This blue clay is 50 to 75 feet in thickness. Beneath it, to a depth of 50 to 100 feet farther, are alternations of sand or gravel in thin beds with beds of compact stony clay of considerable thickness. These beds of sand and gravel yield the artesian water. In much of the district a bed of buried peat is found associated with the first water-bearing sand, showing that it was a marshy land surface prior to the deposition of the overlying blue clay. In a few places beds of peat have been found at two levels in a single well.

Table showing depths to water-bearing strata and heights to which water will rise above surface.

Locality.		Depth.	Height above surface.
		Feet.	*Feet.*
East side of Vermilion marsh		60	4- 5
West side of Vermilion marsh, 1 vein at		75	1
Piper City, 1 vein at		65	1- 2
South of Piper city		9- 23	1- 2
Near county line southeast of Piper City.	First vein	26- 40	1- 2
	Second vein	70- 87	2- 4
Near Ridgeville	First vein	40- 45	Surface.
	Second vein	75	1- 2
Near Lahogue		70- 80	10
Gilman		70-165	1- 4
Near Crescent City		80-120	1- 6
Spring Creek east of Gilman		100-120	(?)
Spring Creek southeast of Onarga		50- 90	(?)
Shavetail Slough		95-100	Surface.
In and near Watseka	First vein	85- 90	1- 6
	Second vein	160-165	1- 6
Ash Grove and vicinity	First vein	40	2- 4
	Second vein	55	2- 4
	Third vein	70- 75	2- 4
Near Cissna Park		48- 55	4- 8
Near Clayton		60- 70	9
Fountain Creek south of Clayton	First vein	50- 55	Surface.
	Second vein	75- 80	1- 2
	Third vein	135-140	3- 4
Near Bulkley	First vein	40- 50	3- 6
	Second vein	80-110	3- 6

The rate of flow varies from a feeble stream, amounting to but 1 to 2 gallons per minute, to a stream flowing 60 or more gallons per minute. Many of the wells flow only 4 or 5 gallons per minute. In most of the wells the stream has a gentle flow, though occasionally it issues from the pipes with considerable force, but even in such instances the water can be made to rise only a few feet above the height at which it pours forth rapidly.

The city of Watseka, with a population of over 2,000, obtains a supply for its waterworks from a single well, though pumps are necessary to obtain an adequate supply. In nearly every village of the district wells may be found having sufficient strength to supply a waterworks system.

In many of the wells a loss of head has been reported amounting to 3 to 4 feet, and occasionally to as much as 8 to 10 feet, in which event they have ceased to flow. A few cases of stoppage of flow occur because of the boring of a well in the vicinity at a lower level, the latter well being sufficiently strong to draw off the head. After a series of dry years, such as have just been experienced, the head appears to have been affected. At Watseka it has decreased about 7 feet in the past few years, so that flows are now obtained only in the lower parts of the town. Many wells show a loss of head amounting to a foot or more, and a still larger number are reported to show a decrease in the rate of flow. It is frequently observed that several wells in close proximity have a tendency to lessen the average rate of flow, and sometimes when a strong well has been obtained in the vicinity of several weak ones the weak wells decrease in flow or stop entirely. These phenomena show that there is a limit to the water supply, and that if the whole region were to be honeycombed with wells the aggregate amount of flow would not increase at anything like the ratio of increase in the number of the wells.

In some cases the wells have ceased flowing because they have become choked with sand. Instances occur where wells have thrown out great quantities of sand and then stopped flowing. It is thought that in such cases the overlying beds may have settled down and shut off the flow, since this phenomenon occurs only where the water-bearing sand bed is very thin, and since it is often the case that borings made within a few rods of a well that has stopped flowing will open a fresh flow.

It has been suggested by Mr. Daniel W. Mead[1] that these wells have their source in the St. Peter sandstone, which he supposes to be covered in this region only by the drift deposits.

No evidence of such a relationship of the sandstone to the drift has been found so far as the writer is aware. Furthermore, as shown below, the supply is from the south instead of the north.

It is generally supposed by the residents of the district that the source is from the great marshes along the Kankakee, which are much of the year covered with water. This can not be the case, however, since the altitude of the marshes is lower than the head of water at the wells.

The source of supply is, without doubt, from the elevated country bordering the well district on the south and west. The gathering ground may include not only the moraine immediately bordering the district but also a plain of considerable elevation lying between it and another moraine a few miles to the southwest. This plain is underlain in places by gravel or material which is quickly absorbent of water, and since the ridge which lies between it and the artesian-well district appears to have been pushed out upon the plain tracts it seems not improbable that the water which falls on the plain may pass northward beneath the ridge along sand or gravel sheets. It appears from borings in the moraine (as indicated further on) that it is composed

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[1] Hydrography of Illinois, p. 21.

largely of till. Should this be the case the somewhat elevated plain southwest of it is probably the chief absorbing area.

The following table of surface elevations and water levels shows an increase in head in passing southward toward this elevated country. The elevations are taken from the profile of the Illinois Central Railway. The water levels in 1895 are slightly lower than shown in this table, but the difference seldom exceeds 5 feet.

Surface elevations and water levels in Iroquois and adjoining counties.

Station.	Distance from Ashkum.	Elevation above tide.	Water level above tide.
	Miles.	*Feet.*	*Feet.*
Ashkum	0	679	657
Danforth	4	667	660
Gilman	7	666	667
Onarga	11	689	674
Ridgeville	13	681	681
Spring Creek Station	14	677	682
Thawville	17	699	697
Bulkley	20	713	697

It appears from this table that there is an increase of head toward the south of nearly 2 feet per mile. An east-to-west line shows a similar rise toward the moraine on the west. Extending the comparisons east from Gilman, it is seen that at Watseka, 12 to 13 miles distant and at an elevation 20 to 25 feet lower than at Gilman, water rises only 2 to 4 feet above the surface, or about the same as at Gilman, while at Iroquois village, 8 to 9 miles farther east, it rises only to the flood-plain of the Iroquois River, which is 10 to 15 feet lower than the height at which it will flow at Watseka. Upon passing to the east from Iroquois into western Indiana, however, there appears to be an eastward rise in the head, a fact which indicates that the supply in that region is not from the southwest, as in the main district, but more probably from the sandy belt around the head of the Iroquois River.

It should perhaps be stated that the rock floor of this flowing-well district stands higher on its north and east borders than beneath the well district, the difference in altitude being 150 feet or more. This rise would cause an upward bending of the drift beds on the border of the district. This bending of the beds may so interrupt the passage of water down the slope toward the northeast as to improve the conditions for obtaining a flow. The great loss of head in that direction seems, however, to indicate that there is a fair escape for waters.

So far as the writer is aware, no chemical analyses of the water from any of these wells have been made. The waters are chalybeate and have laxative properties. They contain so little lime that it is scarcely necessary to "break" the water for laundry purposes. In this respect the deep wells are in striking contrast with the shallow wells that obtain water in or above the blue clay, the latter being strongly impregnated with lime. It is claimed for these waters that no bad effects result from drinking large quantities, where an equal amount of hard water from the shallow wells would be injurious. It is also said that cattle, horses, and other stock prefer the water from flowing wells and keep in better condition when using it than when they drink the hard water of the shallow wells.

The temperature of several of the wells was taken during the autumn months and was found to be quite uniform at about 50° F.

Along the moraine southwest of this district several deep borings have been made for water between Paxton and Roberts, which usually penetrate a large amount of blue till, beneath which sand of considerable depth is often found. The water rises in the wells but does not overflow because of the high altitude of the ridge. A well in sec. 11, T. 24, R. 9 E., reported by George Leeper, of Paxton, penetrates 98 feet of pebbly clay, then 85 feet of sand, and the water rises 130 feet in the well. A well in sec. 2, T. 24, R. 9 E., reported by Mr. Flora, of Roberts, penetrates 120 feet of clay, then 80 feet of sand; the height to which water rises was not ascertained, though it comes nearly up to the surface. A well in sec. 7, T. 25, R. 9 E., also reported by Mr. Flora, penetrates 190 feet of pebbly clay, then 20 feet of sand, and the water rises 150 feet. A well in sec. 31, T. 26, R. 9 E., reported by Mr. Flora, penetrates clay 130 feet, then sand 110 feet, and the water rises 170 feet or to within 70 feet of the surface.

FLOWING WELLS IN NORTHERN VERMILION COUNTY.

Near Marysville, in northern Vermilion County, on a low plain between drift ridges, several flowing wells have been obtained. A number of these wells were made by Mr. George Platt, a well driller, formerly residing at Watseka. Mr. Platt kept no records of individual wells, but furnished the following general statement:

There are three veins of artesian water within 150 feet of the surface, the first being at a depth of 80 to 90 feet, the second at about 125 feet, and the third at 140 to 150 feet. The water will rise 8 to 10 feet or more above the surface, and some of the wells have a flow of several gallons per minute. The following section illustrates the character of the drift penetrated:

Representative section near Marysville, Vermilion County, Ill.

	Feet.
1. Yellow pebbly clay	10–12
2. Blue clay, soft like putty, and containing few pebbles	60–70
3. Hard, stony clay	3
4. Sand and gravel with artesian water	6–10
5. A hard, partially cemented sandy clay	25–30
6. Sand and gravel with artesian water	5
7. Hard, partially cemented sandy clay	15–20
8. Sand and gravel with artesian water	Several.
Depth	140–150

EARLVILLE FLOWING-WELL DISTRICT.

Near Earlville, in northern Lasalle and southwestern Dekalb counties, there is a tract including an area of 30 to 40 square miles in which flowing wells have been obtained. They are found in the southeastern part of T. 36, R. 2 E., the northwestern part of T. 36, R. 3 E., and the southern part of T. 37, R. 3 E.

The wells are seldom more than 50 feet in depth, and a few are scarcely 20 feet. They vary in depth when near together, but this is to be accounted for in part, though not entirely, by the greater depth to which some of them were sunk into the sand from which the water flows. In no instance does water rise more than 10 feet above the surface, and in most cases it rises only 2 to 3 feet. Where the rise is more than 3 feet the wells are favored by being near streams where there is a lower level than on the plain. In some instances there are singular variations within short distances in the absolute height to which water rises. A well at Charles Pratt's residence, in sec. 5, T. 36, R. 3 E., falls short 6 feet of flowing, but a well a few rods from his house on ground 3 feet above the level of the other well rises 1 to 2 feet above the surface. It seems scarcely probable that the two wells have the same source of supply. During seasons of excessive drought nearly all the wells in this district are said to show a lowering of head of a foot or more.

Water will not flow at Earlville, although the level at Big Indian Creek is several feet lower than in section 6 of the same township, where water rises 10 feet above the surface.

It seems probable that the gathering ground for the water is to be found in a sandy tract north of the well district on the inner slope of the moraine. The water which permeates these porous formations would naturally seek outlet in the direction of surface slope unless checked by some obstruction. This course would take it directly beneath the flowing-well district, and the conditions at Earlville suggest the nature of the probable obstruction to the southeastward passage of these subterranean streams. There is here a considerable rise in the rock strata above their level in the flowing-well district. The drift beds sinking into the concavity north of this ledge would produce such an arrangement of the drift strata as would admit the water to the lower beds beneath the flowing-well district, but at the same time not permit it to have adequate outlet over the arching portion at Earlville. Hence, borings made in the region where the water has accumulated, even though at a higher level than the surface near Earlville, afford a freer outlet for the water than its subterranean course.

These flowing wells usually penetrate the following series of drift beds: (1) Soil, (2) yellow pebbly clay, (3) blue bowlder clay, (4) sand or gravel. Occasionally a well penetrates no blue clay, being in pebbly yellow clay to the water-bearing stratum. In some of the shallower wells water is obtained from sand and gravel between the yellow and blue clays. In a few borings, instead of yellow clay there is sand or gravel, underlain by blue clay, beneath which water is obtained.

The water in nearly all the wells is chalybeate, and is considered very wholesome.

The temperature of the wells was taken in the month of September, and in nearly every well it was about 50° F. The flow is very weak in the majority of cases, being scarcely 1 barrel per hour, but a few wells near Big Indian Creek flow several gallons per minute.

Southeast from Earlville about 3 miles, in the valley of Big Indian Creek, are two flowing wells which are only 12 to 15 feet in depth and scarcely differ from the springs abounding along the creek. Both the wells and the springs are slightly chalybeate.

AU SABLE CREEK FLOWING WELLS AND SPRINGS.

In the vicinity of Plattville, in southern Kendall County, there are several flowing wells. Those which flow are confined to the low ground along the creek, but there is a rise of water nearly to the surface on much of the plain lying east of the Marseilles moraine in Kendall and Grundy counties.

The majority of the wells are but 30 to 45 feet in depth, and penetrate about 30 feet of till before entering the water-bearing sand bed. The absorption area is apparently the slope of the moraine to the northwest of the wells, there being a tract of several square miles in which the drift is somewhat sandy and sufficiently porous to absorb much water. The head at Plattville is about 20 feet above the level of Au Sable Creek bed, or not far from the level of the village, 600 feet above tide (Rolfe). The temperature of several of these wells was taken in the month of August and found to be 48° to 50° F. The water is slightly chalybeate. One of the wells belonging to Daniel Platt was found to have a flow of 10 gallons per minute from an aperture with one-half inch diameter. The pipe had a diameter of 2 inches, and the flow is said to be sufficiently strong to fill it with a rapid stream.

Before any wells had been sunk at Plattville this portion of the valley of Au Sable Creek had a group of springs of local reputation, known as the "Au Sable Springs." They appear for more than a mile from a point one-half mile above Plattville to about the same distance below the village. They have apparently the same source as the flowing wells, and the water probably rises through the till which overlies the water bed.

About 1½ miles east of Plattville a flowing well was obtained at a depth of 80 feet after penetrating about 40 feet of rock. This water has a sulphurous taste. Its source is not apparent.

At Millington, about 10 miles west from Plattville, in the valley of Fox River, shallow flowing wells are obtained from the St. Peter sandstone, and similar wells are obtained at Marseilles, as shown further on. In these cases the source of water is probably from the outcrops of the sandstone rather than from the drift.

PALATINE FLOWING-WELL DISTRICT.

In northern Cook County there is a small district, having a radius of about 2 miles, with the village of Palatine as a center, where flowing wells are obtained. In 1887 there were 8 of these wells in the village of Palatine, and at least 25 in the township. The writer has obtained no later information concerning this district. The depth of the wells ranges from 70 to 170 feet, the majority of them being from 125 to 170 feet in depth. Occasionally a well has struck two or more veins from which water will flow, though usually there is but one vein. In the village of Palatine the water rises from the three strongest wells about 10 feet above the level of the track at the depot. These wells do not obtain water from exactly the same depth, but are among the deepest wells in the village. The head is lower in the shallow wells, water rising in some cases but about 5 feet above the level of the depot. It was not determined to what height water rises in wells outside the village as compared with those in the village, since they are scattered widely, and no levelings have been made between the wells. The rate of discharge varies greatly even in the village of Palatine. The strongest well, which is at the cheese factory, flows 60 gallons per minute. The other wells in the village flow but 1 to 6 gallons per minute, and the wells at the farmhouses outside the village seldom flow more than 5 gallons per minute. The water is slightly chalybeate in every well which was examined, and varies greatly in hardness in the different wells. All the water, however, is so hard that it is necessary to "break" it before using it for laundry purposes.

There are many deep wells in the vicinity of Palatine which do not flow even when the surface level is lower than that at the flowing wells. The water supply is apparently from veins whose collecting areas vary in altitude; otherwise the water level would be more uniform.

The collecting area is thought to be in the portion of the moraine west and north of Palatine. The moraine west of Palatine attains an altitude of 100 to 120 feet above the station, and the crest of the moraine in Lake County, a few miles to the north, has nearly as great an altitude. The superficial drainage is very poor north of Palatine, on the divide between Salt Creek and Buffalo Creek, and it is also poor west of Palatine, for there is no stream nearer than Fox River to receive its waters. Consequently, much of the water must evaporate or find outlet by underground passages. There seems to be a sufficient collecting area and also a sufficient variation in altitude to account for the wells and their different water levels.

SALT CREEK FLOWING-WELL DISTRICT.

South of Palatine Township, along Salt Creek and its tributaries, flowing wells are frequently obtained. They differ but little from springs which occur along the creek. There are at least 6 such wells along a tributary of Salt Creek in the eastern part of Schaumburg

Township (T. 41, R. 10 E.), none of which exceed 45 feet in depth. Those along Salt Creek, from Plum Grove, in southern Palatine Township, to the latitude of Elmhurst, in York Township, seldom exceed 30 feet in depth. In Itasca there are a few flowing wells along a tributary of Salt Creek. Of these, the deepest one is but 28 feet. The water here will not rise more than 3 feet above the bed of the creek. This level is 65 to 70 feet lower than the level of the flowing wells in Palatine.

FARMER CITY WATERWORKS WELL.

At Farmer City, in northeastern Dewitt County, some very strong flowing wells have been obtained from the drift. The city well, which supplies the waterworks, is reported to furnish a rapid flow, filling an 8-inch pipe at a level 3 feet above the surface. The well is 176 feet in depth, and has maintained its strong flow from the time it was made, in 1892.[1] The water is described as "soft, with iron," and it is very wholesome

SYCAMORE WATERWORKS WELLS.

The city of Sycamore, the county seat of Dekalb County, is supplied by flowing wells 65 feet in depth. The superintendent of waterworks, Mr. Pike, has estimated the force of the current to be 90 feet per minute from a 2-inch pipe at a level 6 feet above the surface. The water will rise but a few feet higher. The flowing wells can be obtained only on low ground near the Kishwaukee.

WELLS OF MODERATE DEPTH IN ROCK.

In portions of the State where the drift does not furnish an abundance of water wells are frequently sunk into the rock to a moderate depth. They are usually drilled, and have a diameter of about 4 inches. Usually these wells find sufficient water to justify the erection of a windmill, the yield being at least 3 to 4 gallons per minute and in some cases many times that amount. In this class of wells the head is seldom such as to cause an overflow, and is usually but a few feet above the level at which water is struck.

The data concerning this class of wells (set forth in the following table) have been mainly obtained in response to the circular of inquiry concerning city water supply, and in answer to the two questions: "At what depth is water most abundant in the wells?" and "What range in depth have the wells?" The replies to these questions are given in the majority of the schedules, and it appears that but a small part of the towns have found their most abundant supply of water from this class of wells. In many cases, however, no tests have been made, for the shallow wells have proved sufficient for ordinary demands. The conditions in neighboring rural districts, as well as in villages, are represented.

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[1] The writer visited this well in June, 1896, and found that its head had become lowered to about 5 feet below the surface.

Table of wells from rock at moderate depths.

Locality.	Best water horizon.	Deepest wells.
	Feet.	*Feet.*
Amboy	20	(?)
Anna and vicinity	40	60
Ashley	33	40
Augusta and vicinity	60	265
Barry	65	90
Cairo	70	200
Casey	25	60
Chenoa	150	150
Columbia	30	45
Dallas City	30	150
Earlville	150	150
Equality	30	40
Erie and vicinity	30	30
Fairfield and vicinity	50 to 70	300
Forreston	50 and 300	300
Freeport	Variable.	90
Gardner coal shafts	100	....
Geneseo	120	....
Golconda	30 to 40	40
Hutsonville	30	30
Ipava and vicinity	100	150
Kankakee	Variable.	70
Kinmundy	20	30
Knoxville	20 to 40	40
Lawrenceville	60	60
Lebanon and vicinity	150 to 200	200
McLeansboro	Variable.	160
Marseilles (artesian)	150	200
Martinsville	Variable.	80
Mendon	70 and 200	400
Mendota	175 to 400	400
Millington (artesian)	50	70
Momence	30	80
Morrison	35 and 75	75
Mount Carmel	Variable.	40
Mount Sterling	Variable.	75
Nauvoo	Variable.	40
Nashville	Variable.	45
Neoga and vicinity	(?)	285
Oakland	120	120
Oregon	30	200
Pecatonica	80 to 125	125

Table of wells from rock at moderate depths—Continued.

Locality.	Best water horizon.	Deepest wells.
	Feet.	*Feet.*
Quincy	90 to 200	200
Redbud (artesian)	40	....
Rochelle	30 to 40	60
Sterling (artesian)	35	....
Virden	30	50
Vienna	50	60
Warren	80	125
Waterloo	Variable.	80
Wheaton and vicinity	150 to 200	200
Whitehall	50	50

CHAPTER VIII.

ARTESIAN WELLS.

GENERAL STATEMENT.

Since the essential conditions for obtaining artesian wells have been discussed at some length by Prof. T. C. Chamberlin in a report of this Survey,[1] only a brief outline of these conditions is here attempted. That report now being out of print and perhaps not accessible to every-one interested in the subject, reference is also made to Johnson's Cyclopædia, which contains a brief discussion of artesian-well conditions by Mr. F. H. Newell.[2] A similar discussion, by Mr. Robert T. Hill, appears in a recent number of the Popular Science Monthly.[3]

The essential conditions for artesian wells are: (1) A suitable exposure of a porous rock in a humid region, i. e., a favorable absorbing area; (2) the extension of this porous bed from the absorbing area out underneath regions having a lower altitude, i. e., a favorable transmitting area; (3) a partial or full obstruction to the escape of the waters at

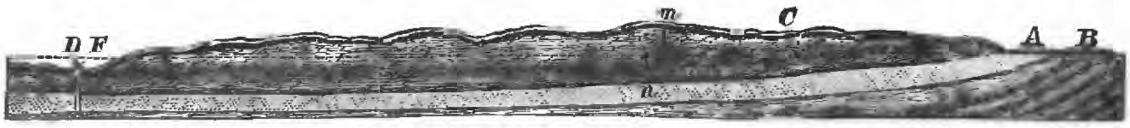

FIG. 66.—Section illustrating the aid afforded by a high water-surface between the fountain head and the well. (After T. C. Chamberlin; see Fifth Ann. Rept. U. S. Geol. Survey, fig. 15, p. 140.)

a lower level than the absorbing area. The porous rock is usually confined between beds which are less porous and which act as a partial or complete obstruction to the escape of the waters. It is not necessary, however, that these beds should be perfectly water-tight; indeed, such is rarely the case. It is only necessary that the confining beds should be such as to prevent most of the water from escaping.

In some cases the water contained in semiporous beds overlying the porous rock aids in preventing the escape of water from the porous bed at points between the absorbing area, or fountain head, and the well. This is illustrated in the section (fig. 66), and as it is a condition which prevails quite extensively in northern Illinois the subject is worthy of discussion in this place.

The absorbing area for the artesian waters of northern Illinois is in southern Wisconsin, the porous rock thence dipping southward to

[1] Requisite and qualifying conditions of artesian wells, by T. C. Chamberlin: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 131–173.

[2] Johnson's Universal Cyclopædia, Vol. I, 1893, Artesian Wells, pp. 347–349.

[3] Artesian waters in the arid region, by Robert T. Hill: Pop. Sci. Monthly, March, 1893.

northern Illinois. Between this absorbing area and the wells is a district in which the porous bed is overlain by limestone or semiporous rock and also by drift beds which afford much opportunity for transmission of water. These overlying beds, however, have altitudes fully as great as portions of the absorbing area, and hence, when filled with water, the downward pressure equals or exceeds that of the upward pressure of water from the porous bed, and thus they prevent escape as effectually as a series of impervious beds. In connection with his illustration of this condition, Professor Chamberlin remarks (p. 140):

> I conceive that one of the most favorable conditions for securing a fountain is found where thick, semiporous beds, constantly saturated with water to a greater height than the fountain head, lie upon the porous stratum and occupy the whole country between the well and its source, as illustrated by fig. 15.[1] This is not only a good but an advantageous substitute for a strictly impervious confining bed. Under these hydrostatic conditions limestone strata reposing on sandstone furnish an excellent combination.

Professor Chamberlin's ideal section should be compared with the similar actual section from the Wisconsin River southward across Illinois (fig. 67), and with the section from Galena to Olney, Ill. (fig. 68).

The variability of head displayed by wells in northern Illinois which obtain their main supply from the St. Peter formation is probably largely due to the influx of water from overlying beds in the district between the fountain head and the well. In the northeastern counties of Illinois, especially where the drift deposits are very thick and contain a large body of sand or gravel filled with water, the head is found to be above the normal. In such cases the collecting area or fountain head should perhaps be made to include the elevated semiporous beds as well as the outcrops of the porous beds. In some districts there is danger of loss of head by escape downward from the porous bed, but in Illinois, although these underlying beds are usually semiporous, the conditions are very unfavorable for the escape of water, for they have few outcrops at points below the level of the fountain head.

The comparatively low altitude of the absorbing area presents a disadvantage. It contains but little ground exceeding 1,000 feet above tide (see map, Pl. CXI), and much of its surface is below 800 feet. Some outcrops along the valleys of Wisconsin are but little above 600 feet. Therefore, with excellent conditions for preserving the head, flows can scarcely be expected at altitudes much greater than the lowest outcrops. It is a matter of surprise that in places they rise above 700 feet.

It is not easy to separate wells which flow from those which do not. In many cases the head is so nearly coincident with the altitude of the well mouth that a well may flow under favorable conditions and cease to flow under unfavorable conditions. For example: In Chicago the water in wells first sunk rose several feet above the surface; but when

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[1] Fig. 66 in this report, on next preceding page.

MAIN ABSORBING AREAS FOR THE POTSDAM AND ST. PETER FORMATIONS

COMPILED CHIEFLY FROM STATE GEOLOGICAL MAPS

BY FRANK LEVERETT, 1896

Scale

25 0 25 50 75 100 Miles

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the number of wells had greatly increased and large drafts were made by pumping, the wells ceased flowing. There are portions of Chicago near

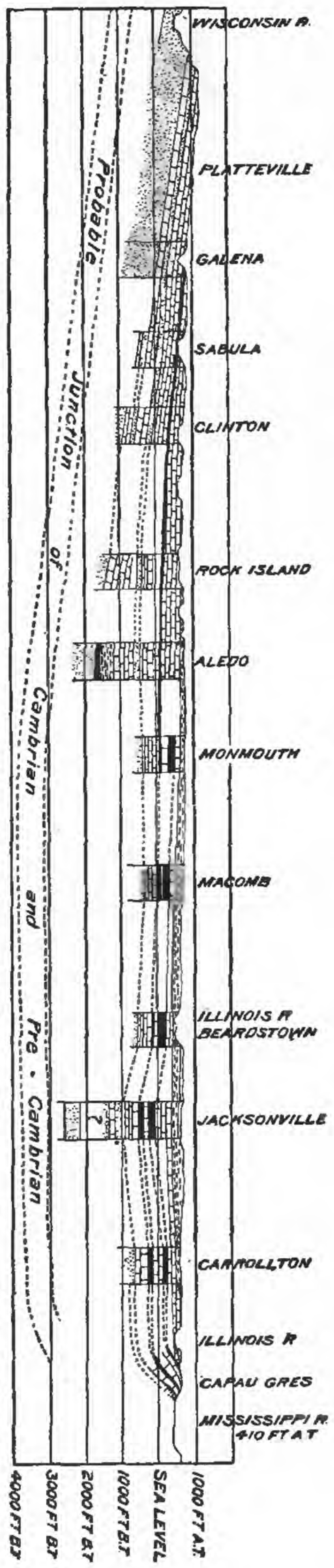

FIG. 67.—Section A-A, from the Wisconsin River in western Wisconsin southward to Cap au Grès, near the mouth of the Illinois.

This section shows a line through a region where wells are very successful. Northward from Aledo the section shows but one shale bed (the Hudson River), and this is wanting north from Galena. But south from Aledo the Kinderhook and Coal Measures shales comprise a considerable portion of the section. Vertical scale is 40 times the horizontal.

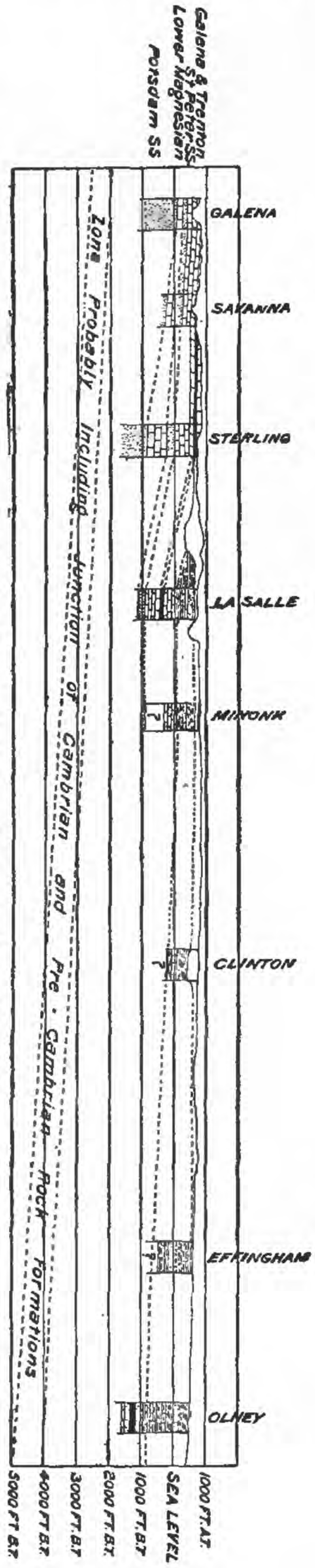

FIG. 68.—Section B-B, from Galena to Olney, Ill.

This section leads through the deep part of the Coal Measures basin from Lasalle to Olney. Wells are successful from Minonk northward. Vertical scale is 40 times the horizontal.

the stock yards where it is reported that wells do not flow except for a brief period each week after the Sunday intermission from pumping.

In some towns wells flow if properly constructed, while others at similar altitudes do not quite reach the surface. It seems scarcely legitimate to restrict the term "artesian" to wells which chance to be so favorably situated or constructed as to flow, and to exclude those which are less fortunately situated or constructed, for the class of well is the same in both cases. Furthermore, the matter of flow is of little consequence to many of the prospectors of wells, for it is found that by the use of pumps a larger amount of water can be obtained than from the natural flow. In such cases the water surface is kept down by the pumping much of the time below the level of the well mouth. In the present paper the term artesian is applied to wells which flow and also to those which do not flow but which have a head similar to that of the flowing wells and are derived from the same water-bearing rock formations.

In the tables a few wells appear which have a remarkably high water level. For example, the Dekalb waterworks well, which obtains much water from the St. Peter sandstone, stands at 772 feet above tide, and others in the city at over 800 feet, but those wells receive also the water from glacial deposits, which has a greater head than that from the St. Peter sandstone. It is thought also that the well at Harvard has its head raised to the high level of 894 feet by access of surface water. The well at Amboy, with a head 781 feet above tide, began flowing when only 390 feet in depth, and though the lower water beds increase the quantity, they do not increase the head; indeed, it is not improbable that the head from these lower veins is lower than that from the upper.

Wells along the Mississippi, on the Iowa side of the river, are included in the tables, since they aid in showing the conditions on the extreme border of the State.[1]

Before entering upon the discussion of the wells, a brief review of the rock formations of the region will be of advantage.

THE PALEOZOIC ROCKS IN ILLINOIS.

DISTRIBUTION OF OUTCROPS.

The indurated rocks of Illinois, so far as exposed in outcrops or by borings, are all included in the Paleozoic system. The Tertiary formations of the southern end of the State and the glacial deposits which mantle much of the State are in the main but partially lithified. The extent of each of the main rock formations is indicated upon the geological map (Pl. CXII), which is based upon Worthen's map of Illinois, published in 1875, and Phinney's Indiana map, published in the Eleventh Annual Report of the United States Geological Survey.

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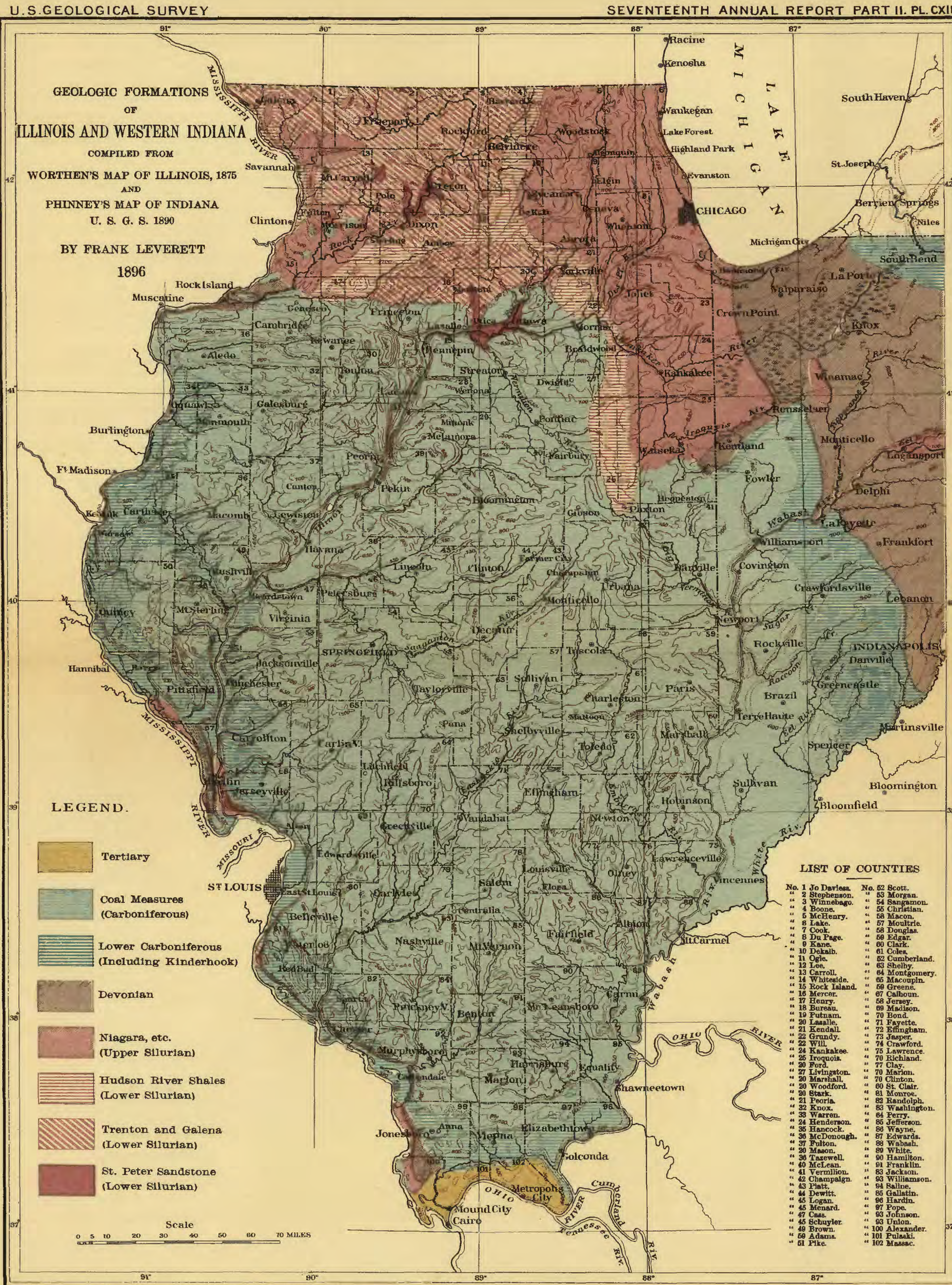
[1] The conditions for artesian wells in Indiana will be discussed in another paper, for which considerable material is already collected. The artesian wells of Iowa are now under investigation by Prof. W. H. Norton, of the Iowa Geological Survey, and will be discussed by Mr. Norton in an early report of that Survey.


GEOLOGIC FORMATIONS
OF
ILLINOIS AND WESTERN INDIANA
COMPILED FROM
WORTHEN'S MAP OF ILLINOIS, 1875
AND
PHINNEY'S MAP OF INDIANA
U. S. G. S. 1890
BY FRANK LEVERETT
1896
LEGEND.
Tertiary
Coal Measures (Carboniferous)
Lower Carboniferous (Including Kinderhook)
Devonian
Niagara, etc. (Upper Silurian)
Hudson River Shales (Lower Silurian)
Trenton and Galena (Lower Silurian)
St. Peter Sandstone (Lower Silurian)
Scale
0 5 10 20 30 40 50 60 70 MILES
LAKE MICHIGAN
CHICAGO
ST LOUIS
SPRINGFIELD
INDIANAPOLIS
MISSISSIPPI RIVER
OHIO RIVER
LIST OF COUNTIES
No. 1 Jo Daviess.
" 2 Stephenson.
" 3 Winnebago.
" 4 Boone.
" 5 McHenry.
" 6 Lake.
" 7 Cook.
" 8 Du Page.
" 9 Kane.
" 10 Dekalb.
" 11 Ogle.
" 12 Lee.
" 13 Carroll.
" 14 Whiteside.
" 15 Rock Island.
" 16 Mercer.
" 17 Henry.
" 18 Bureau.
" 19 Putnam.
" 20 Lasalle.
" 21 Kendall.
" 22 Grundy.
" 23 Will.
" 24 Kankakee.
" 25 Iroquois.
" 26 Ford.
" 27 Livingston.
" 28 Marshall.
" 29 Woodford.
" 30 Stark.
" 31 Peoria.
" 32 Knox.
" 33 Warren.
" 34 Henderson.
" 35 Hancock.
" 36 McDonough.
" 37 Fulton.
" 38 Mason.
" 39 Tazewell.
" 40 McLean.
" 41 Vermilion.
" 42 Champaign.
" 43 Piatt.
" 44 Dewitt.
" 45 Logan.
" 46 Menard.
" 47 Cass.
" 48 Schuyler.
" 49 Brown.
" 50 Adams.
" 51 Pike.
No. 52 Scott.
" 53 Morgan.
" 54 Sangamon.
" 55 Christian.
" 56 Macon.
" 57 Moultrie.
" 58 Douglas.
" 59 Edgar.
" 60 Clark.
" 61 Coles.
" 62 Cumberland.
" 63 Shelby.
" 64 Montgomery.
" 65 Macoupin.
" 66 Greene.
" 67 Calhoun.
" 68 Jersey.
" 69 Madison.
" 70 Bond.
" 71 Fayette.
" 72 Effingham.
" 73 Jasper.
" 74 Crawford.
" 75 Lawrence.
" 76 Richland.
" 77 Clay.
" 78 Marion.
" 79 Clinton.
" 80 St. Clair.
" 81 Monroe.
" 82 Randolph.
" 83 Washington.
" 84 Perry.
" 85 Jefferson.
" 86 Wayne.
" 87 Edwards.
" 88 Wabash.
" 89 White.
" 90 Hamilton.
" 91 Franklin.
" 92 Jackson.
" 93 Williamson.
" 94 Saline.
" 95 Gallatin.
" 96 Hardin.
" 97 Pope.
" 98 Johnson.
" 99 Union.
" 100 Alexander.
" 101 Pulaski.
" 102 Massac.
JULIUS BIEN & CO. N.Y.

In the northern part of the State, Lower Silurian limestones of the Trenton group and Upper Silurian of the Niagara group constitute the chief surface rocks. The former group is found over several counties in the northwest corner, while the latter overlaps it on the east and south. The intermediate Hudson River or Cincinnati group consists largely of shales and shaly limestones, and has but a limited outcrop. When unprotected by the Niagara it has been unable to resist erosion. It usually appears, therefore, only for a short distance beyond the borders of the Niagara.

The St. Peter sandstone, which underlies the Trenton limestone, is well exposed for a few miles above Utica, on the Illinois, and on the lower courses of Fox and Vermilion rivers. It is exposed for a few miles on Rock River and its tributaries in the vicinity of Oregon, and also for a few miles near the head of Elkhorn Creek, 6 or 8 miles northwest from Polo. The only remaining known outcrop of this sandstone in the State is near the junction of the Illinois and Mississippi, where an upheaval brings it to view.

A limestone which underlies the St. Peter sandstone, and which is known in Illinois and Wisconsin by the rather vague term "Lower Magnesian limestone," has a very limited outcrop at Utica and also on Elkhorn Creek near Polo. It is supposed by Hon. James Shaw, formerly of the Illinois Geological Survey, to be exposed in the bed of Rock River a few miles below Oregon.[1]

A line running from Rock Island eastward across the State to Kankakee passes near the south border of the main Silurian outcrops. South from this line the surface rocks are mainly Coal Measures, consisting chiefly of shales and shaly sandstones, with which thin beds of limestone, coal, etc., are associated. In southern Illinois, however, heavy sandstone and conglomerate beds occur at the base of the Coal Measures. Limestones of the Lower Carboniferous, or Mississippian series, form the surface rock along the Mississippi throughout most of the western boundary south from Rock Island, Coal Measures strata in the immediate bluffs occurring only for a few miles south from Rock Island and for a few miles below Alton, and Devonian and Silurian strata only at a few points where upheavals have been sufficient to bring them to view. Lower Carboniferous limestones also border the lower course of the Illinois for a distance of about 80 miles. They appear also on the south slope of the Ozark ridge, in southern Illinois. In the district above the mouth of the Illinois, the Lower Carboniferous rocks consist of the St. Louis, Keokuk, and Burlington limestones. Below the mouth of that stream St. Louis limestone and Chester limestone and sandstone constitute the main representatives, though thin beds of Burlington and Keokuk outcrops occur where upheavals have brought them to view.

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[1] Geology of Illinois, Vol. V, pp. 118, 119.

ALTITUDE AND ATTITUDE OF THE STRATA.

By combining the records of wells and coal shafts or borings with the study of outcrops a general conception may be obtained of the folds and inclinations of the rock formations. A north-to-south section shows a general but very gradual southward dip of the formations, terminated at the south by the axis of upheaval which, as above noted, leads eastward across the State from Grand Tower to Shawneetown. The descent probably amounts to 2,500 to 3,000 feet in the 350 miles from the north to the south end of the State. It is probable that any meridian chosen as a line for a section would show slight undulations, carrying the strata up or down 100 to 200 feet or more from a uniform grade, but so far as known no prominent west-to-east axis of upheaval crosses the State north of the one just noted. Mention should be made of a low arch separating the Illinois-Indiana coal field from the Michigan coal field, which is traceable from Lasalle County eastward, and which connects on the southeast with the "Cincinnati arch." This arch is, however, so low in eastern Illinois as to bring the Lower Silurian strata scarcely 200 feet above their level 20 or more miles to the north. This southward rise of perhaps 10 feet per mile for a distance of 20 miles is but a slight deflection in the long line of southward descent from Wisconsin to southern Illinois, in which the formations descend not less than 2,500 feet.

West-to-east sections are less uniform in the inclination of strata than the north-to-south sections. Sections across the northern part of the State present two blocks of strata, each dipping gradually to the east, separated by an abrupt fold or line of disturbance. At this fold the block on the east rises abruptly several hundred feet above the neighboring portion of the western block. It is along this line of disturbance that the St. Peter and Lower Magnesian strata are brought to view on the Illinois and Rock rivers and on Elkhorn Creek. Its trend from the Illinois River northward is about southeast to northwest. Sections in the lead region indicate that it continues in subdued form some distance into southwestern Wisconsin. Its southward continuation from the Illinois is readily traceable as far as Livingston County by disturbances shown in coal shafts, as noted by the Illinois Survey. Farther south its course is less definitely known, the only source of knowledge being the records of borings which have been put down to test the field for coal, gas, oil, or water. These indicate a condition similar to that of northern Illinois, at least as far south as Tuscola, in Douglas County. The borings show that the base of the Coal Measures is reached at a much higher level along a line leading from Utica southward to Tuscola than along a parallel line a few miles to the west, and slightly higher than on a parallel line a few miles to the east. This may be seen by the following table:

Altitudes of the base of the Coal Measures along three lines.

West of fold:
- Lasalle, sea level.
- Fairbury, 120 feet above tide, or less.
- Clinton, 200 feet below tide.
- Decatur, 200 feet below tide.

On the fold:
- Utica, 580 feet above tide.
- Chatsworth, 515 feet above tide.
- Champaign, 317 feet above tide.
- Tuscola, 473 feet above tide.

East of fold:
- Morris, 430 feet above tide.
- Milford, 466 feet above tide.
- Danville, 300 feet above tide.
- Montezuma, Ind., 200 feet above tide.

This disturbance has been made a subject of special study by Prof. J. A. Udden at the point where it crosses the Illinois, and he gives the following description of the structural features along a line leading from Rock Island eastward through this point to eastern Illinois. The section from Davenport eastward past Joliet (fig. 69) follows nearly the line here described.

> We see two blocks of horizontal or only very slightly inclined strata separated by a monoclinal fold. The downthrow and the trough limb is on the west, while the upthrow and the arch limb is on the east. The total displacement of the Silurian strata amounts to 1,575 feet, while the Carboniferous beds are displaced only about 625 feet. The trend of the axis of disturbance is considerably west of north, the strike of the outcrops of the upturned Coal Measures being about N. 30° W. The average dip in the displacement at Lasalle is about 22° for the Silurian rocks and about 8° for the rocks of the Coal Measures. The block of strata west of the monocline is nearly horizontal in an east-to-west direction from Rock Island to Annawan and from Princeton to Lasalle, but between Princeton and Annawan there is a dip to the east of about 25 feet to the mile, or there is a concealed displacement of that extent between these two places. This dip may be partly accounted for by the dip to the south which is found along the whole section. The block of strata on the east of the monocline has a nearly uniform dip to the east of about 12 feet to the mile.[1]

The Coal Measures strata of central Illinois apparently reach about their lowest level along a line shown in fig. 68, leading from Lasalle southward parallel with the line of disturbance and but a few miles west of it. There is over much of western Illinois a gradual descent from the western border of the State to this line, averaging in the latitude of Peoria about 7 feet per mile and in the latitude of Springfield about 10 feet per mile. The eastward descent across western Illinois appears to continue gradual as far south as the Cap au Grès upheaval, near the mouth of the Illinois, and, so far

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[1] Final Report, Illinois Board of World's Fair Commissioners, 1895, pp. 144, 145.

as known to the writer, there is no marked disturbance along the Mississippi north from that point.

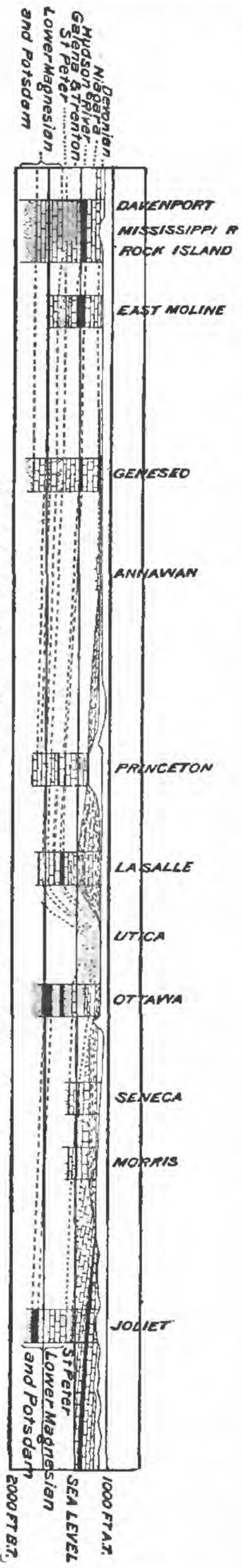

Fig. 69.—Section C-C, from Davenport, Iowa, to Joliet, Ill. This section shows the monoclinal fold which passes just east of Lasalle, with the nearly horizontal blocks on either side. Vertical scale is 20 times the horizontal.

From the Cap au Grès disturbance southward to the Ozark ridge, in southern Illinois, a different field is entered. Disturbances are frequent along the Mississippi. There is also in this district a great descent in the floor of the Coal Measures within a few miles east of the Mississippi. Thus, in passing from the east bluff of the river in western St. Clair County eastward to Belleville a descent of 650 feet is made within a distance of 10 miles. In the vicinity of Murphysboro the Coal Measures floor ranges from 200 feet below sea level to 800 feet above within a distance of 10 miles. The deep portion of the Coal Measures basin seems, therefore, to approach the Mississippi closely from near the mouth of the Illinois southward, and, so far as can be learned from borings, extends eastward at least to the Indiana line. The lowest known points in the Coal Measures floor are in the southeastern part of the State—their level at Olney being about 800 feet and at Shawneetown 1,100 feet below sea level. A great depth is reached in southwestern Illinois, however, the floor at Coulterville, in Randolph County, only 25 miles from the Mississippi, being 325 feet below tide, and at Highland, about 25 miles from East St. Louis, the level is apparently 477 feet below tide.

ALTITUDE OF THE BASE OF THE COAL MEASURES.

In the following table an alphabetical list of the principal borings in the coal field of Illinois is presented which throws light upon the altitude of the floor of the Coal Measures basin. Where borings reach a definite horizon near the base of the Coal Measures, estimates have been made for the level of the floor, and are so indicated. When borings have apparently reached the lower coal, but not the rock floor, a minus sign is affixed to indicate that the base is still lower.

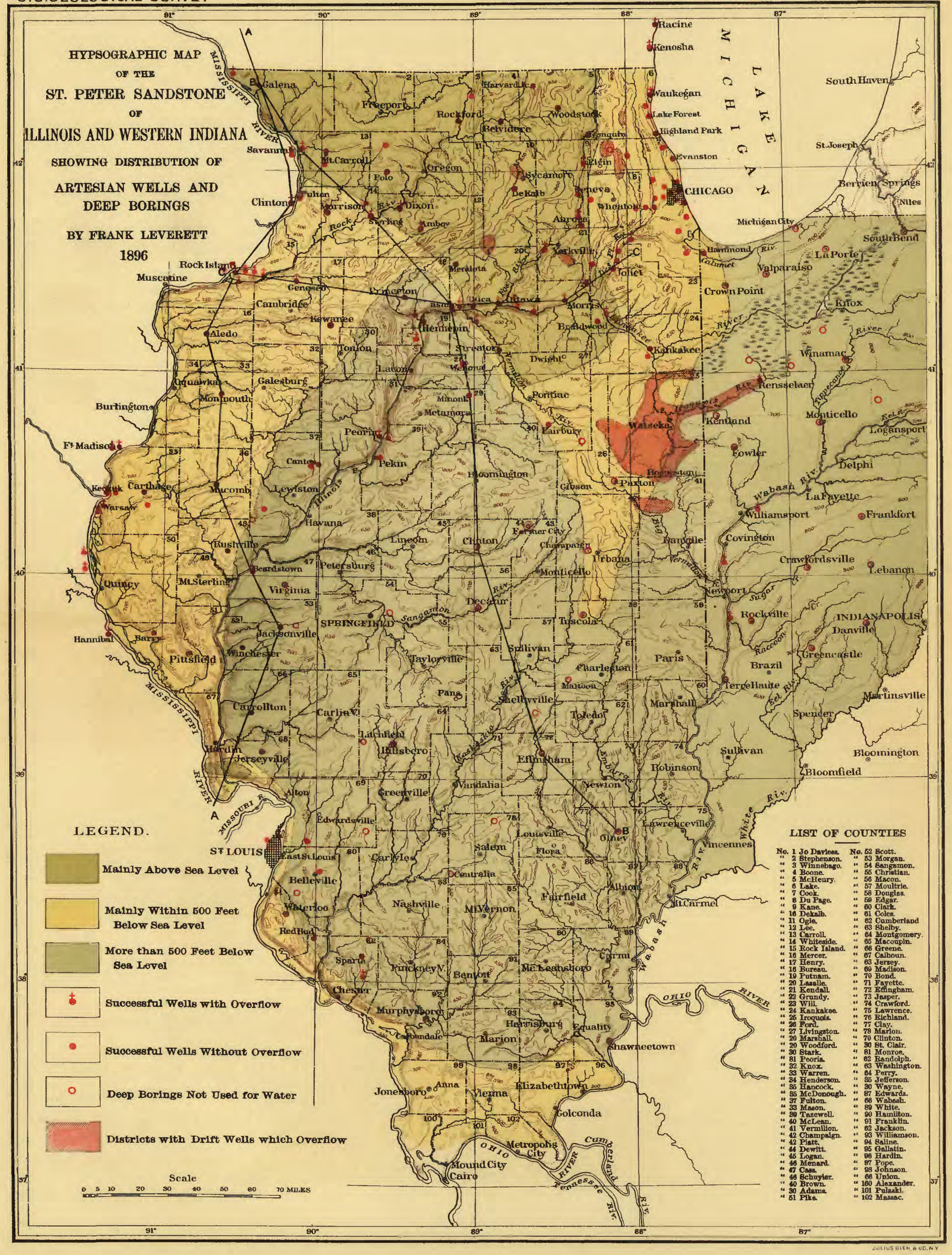

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Table showing altitudes of base of Coal Measures.

Location.	Altitude.		Situation.
	Above tide.	Below tide.	
	Feet.	*Feet.*	
Annawan	466		On western block.
Beardstown (est.)	450		Do.
Belleville	0		Basin in southern Illinois.
Braidwood	446		On eastern block.
Canton	360		On western block.
Carrollton	545		Do.
Champaign	317		On eastern block.
Chatsworth	515		Do.
Clinton		200	In trough.
Coulterville		325	Basin in southern Illinois.
Danville	300		On eastern block.
Dawson (est.)		85	On western block.
Decatur (est.)		200	In trough.
East Peoria	185		On western block.
Effingham (est.)		775	Basin in southern Illinois.
Fairbury	120—		In trough.
Franklin	341		On western block.
Gardner	420—		On eastern block.
Geneseo	520		On western block.
Gibson	575?		On eastern block.
Girard (est.)	50		On western block.
Hennepin		130	In trough.
Highland		477?	Basin in southern Illinois.
Hillsboro		160	On western block.
Ipava	497		Do.
Jacksonville	350		Do.
Jerseyville (est.)	600		Do.
Lasalle	0		In trough.
Litchfield		142	On western block.
Macomb	555		Do.
Marseilles	417		On eastern block.
Mattoon		270	In trough.
Millstadt	375?		Basin (rim) southern Illinois.
Milford	466		On eastern block.
Morris	430		Do.
Monmouth	666		On western block.
Montezuma, Ind	200		On eastern block.
Murphysboro		192	Basin in southern Illinois.
Olney		795	Do.
Pana (est.)		325	In trough.

Table showing altitudes of base of Coal Measures—Continued.

Location.	Altitude.		Situation.
	Above tide.	Below tide.	
	Feet.	*Feet.*	
Peoria	186		On western block.
Pontiac	407—		On eastern block.
Prairie City	467		On western block.
Princeton	120		In trough.
Riverton		112	On western block.
Rock Island	600		Do.
Shawneetown		1, 100	Basin in southern Illinois.
Smithboro		250	Do.
Sparta	138		Basin (rim) in southern Illinois.
Steeleville	150		Do.
Streator	377		On eastern block.
Tuscola	473		Do.
Waverly	286		On western block.
Winchester	450		Do.

ALTITUDE OF ST. PETER SANDSTONE IN ILLINOIS.

For the northern portion of the State, where the Coal Measures are absent, the variations in altitude of formations may perhaps be best shown by a hypsographic map of the St. Peter (Pl. CXIII), which is supplemented by the following table of altitudes of the St. Peter sandstone. This formation in western Illinois lies 1,000 to 1,300 feet below the base of the Coal Measures. In eastern Illinois, near the northern border of the coal field, it is only 300 to 600 feet below that base, because of the absence of Devonian and Lower Carboniferous formations. These formations soon appear, however, in passing southward, and the interval becomes as great as in western Illinois. At Danville it appears to be nearly 1,300 feet. It is probable that in southern Illinois the average interval between the base of the Coal Measures and this formation is not less than 1,200 feet, but there are no borings to test the matter.

Altitudes of top of St. Peter sandstone in Illinois.

Location.	Altitude.		Thickness.	Situation.
	Above tide.	Below tide.		
	Feet.	*Feet.*	*Feet.*	
Aurora		20	236	On eastern block.
Beardstown		605	(?)	On western block.
Braidwood	57		210	On eastern block.
Canton		753	273	On western block.

Altitudes of top of St. Peter sandstone in Illinois—Continued.

Location.	Altitude.		Thickness.	Situation.
	Above title.	Below tide.		
	Feet.	*Feet.*	*Feet.*	
Cap au Grès	550		(?)	Uplift in southwestern Illinois.
Carthage		297	(?)	On western block.
Carrollton		590	(?)	Do.
Chicago		225±	200±	On eastern block.
Danville		1,090	35	Do.
Davenport, Iowa		370	130	On western block.
Elgin	61±		110	On eastern block.
Elkhorn Creek	850		50+	On axis of upheaval.
Evanston		222	420?	On eastern block.
Galena	445		145	On western block.
Geneseo		428	220	Do.
Hammond, Ind		460	190	On eastern block.
Harvard	295		210	Do.
Highland Park		320	200	Do.
Ipava		630	290	On western block.
Jacksonville		900	319	Do.
Jerseyville		738	200	Do.
Joliet		91	210	On eastern block.
Kankakee		280	(?)	Do.
Keokuk, Iowa		318	110	On western block.
Lake Bluff		258	167	On eastern block.
Lasalle		907	175	In trough near axis.
Macomb		435	225	On western block.
Mendota	415		(?)	Near axis of upheaval.
Milan		364	195	On western block.
Millington	600		(?)	Small anticline.
Moline		371	216	On western block.
Monmouth		336	(?)	Do.
Morgan Park		405	(?)	On eastern block.
Morris	180		(?)	Do.
Morrison		100	200	On western block.
Near Oregon (est.)	850		185	On axis of upheaval.
Ottawa	483		138	On eastern block.
Princeton		900	160	In trough.
Rock Island		364	272	On western block.
Rockford	558		225	On eastern block.
Seneca	250		220	Do.
Sterling		33	300	On western block.
Winnetka		281	212	On eastern block.

THICKNESS OF THE PALEOZOIC FORMATIONS.

In the northern part of Illinois the thickness of the Paleozoic rocks is probably much less than in the central and southern portions, since in places only the Lower Silurian and Cambrian are present. No borings have reached the base of these formations, though there are several in the northern part of the State which exceed 2,500 feet in depth. From what is known of the thickness of the Lower Silurian and Cambrian in adjacent parts of Wisconsin, it seems scarcely probable that the thickness in the northern part of Illinois greatly exceeds the depth of the borings. Probably 3,000 feet at the State line would be a liberal estimate.

Concerning the thickness in southern Illinois, nothing definite is known further than the fact that Coal Measures there have a thickness of 1,200 to 1,500 feet, and that at St. Louis, Mo., a well passes through about 3,680 feet of Paleozoic strata below the Coal Measures before entering granite or pre-Cambrian rocks. The St. Louis well probably shows no greater thickness of rocks between the Coal Measures and the pre-Cambrian than will be found beneath much of southern Illinois. On the contrary, it seems probable that because of Devonian and Chester formations, which are present in considerable thickness beneath portions of southern Illinois and are not present in the St. Louis well, the thickness of the Paleozoic rocks of such portions of southern Illinois may exceed by several hundred feet the combined thickness of the Coal Measures and of the rocks penetrated in the St. Louis well. As this combined thickness is about 5,000 feet, it seems probable that the maximum thickness of the Paleozoic rocks in southern Illinois will be found to reach nearly 6,000 feet, or about double the amount thought to be present in northern Illinois.

STRUCTURE OF THE ROCK FORMATIONS.

The writer's knowledge of the formations aside from outcrops has been obtained mainly from the records of wells or other borings which have been made either by drillers or by persons who were present during the drilling of a well. Only a few samples of rock drillings have been personally examined. Some of the records appear to have been kept with care, and much discrimination has been used in classifying the rocks; but the majority indicate only in a partial or crude manner the features of the formations. For example, in the best records the several classes of limestone or shale or sandstone are clearly recognized, but in most records there is no attempt at separation beyond that of the general groups—sandstone, shale, and limestone. In cases where limestones are sandy and sandstones are somewhat calcareous there is often a doubt as to the correctness of the interpretation, even of the general groups. Such being the condition of knowledge of the structure, it seems unwise to publish the majority of the records which have been examined. Fortunately, Prof. J. A. Udden has had opportunity to carefully examine drillings from several of the wells in the vicinity of Rock Island, and his report upon this study is presented herewith. (See Chapter X.) This report, with the sections which accompany it, serves to indicate the character of the formations from the Devonian to the Potsdam in that part of Illinois.

From records in the writer's possession, together with those which have already appeared in print, sections have been made which set forth the structure along several lines traversing the State in various directions. One of these sections passes through Rock Island in a north-to-south course and indicates the changes in thickness and structure of the formations which occur in that direction (see fig. 67). Another leads eastward from near Rock Island to Joliet, showing the changes in dip, structure, and thickness in that direction (see fig. 69). A third section leads from Galena southeastward beneath the Coal Measures basin (see fig. 68). A section across southern Wisconsin from Prairie du Chien to Milwaukee, obtained from Professor Chamberlin's geological map of Wisconsin (see fig. 70), is also given.

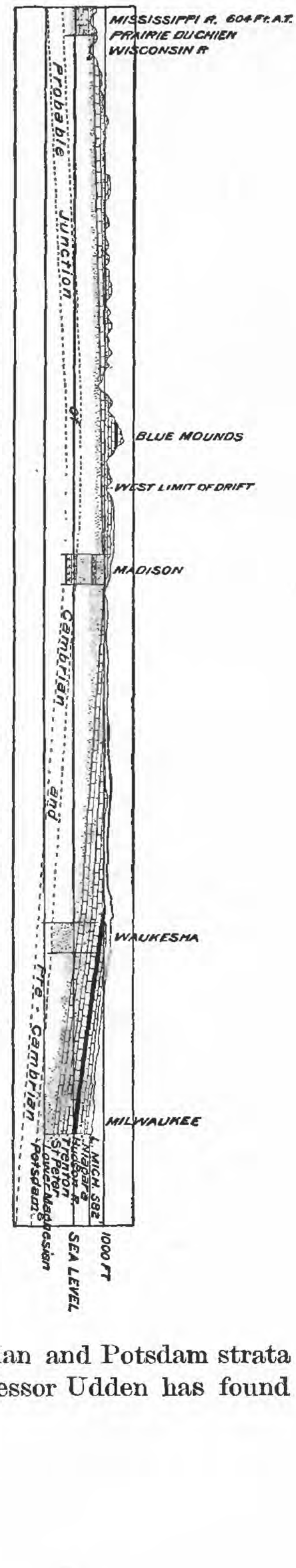

FIG. 70.—Section D-D, across southern Wisconsin from Prairie du Chien to Milwaukee. This section is reduced from Professor Chamberlin's section accompanying his geological map of Wisconsin, published by the Wisconsin Survey. The St. Peter and Potsdam are here separated by only a thin limestone formation. Vertical scale is 25 times the horizontal.

It will be observed that shale constitutes but a small part of the sections outside the Coal Measures area, the greater part of the section being limestone. The sandstones from which flowing wells are obtained apparently have found in the limestone cover as complete a check to the escape of water as would have been made by shale. The district to the west and north of the Coal Measures area is fully as productive in artesian flows as that within the limits of this formation.

The border line between the Lower Magnesian and Potsdam strata has not been satisfactorily determined. Professor Udden has found difficulty, even with the drillings before him, in deciding upon its place. His recognition of the close similarity between the Wisconsin Potsdam and certain beds in the wells at Rock Island and Davenport, however, makes it seem probable that the Lower Magnesian beds there have a thickness of about 800 feet.[1] As is well known, this formation has in southern Wisconsin and northern Illinois a thickness of only 200 feet. Whether this rapid southward increase in thickness prevails over the entire width of Illinois is not determined, though it seems probable that such is the case. A few carefully kept records of wells which penetrate these beds are herewith presented, since they may aid in future interpretations. The records of wells at Ottawa and Joliet were furnished by the driller, A. K. Wallen, of Morris. The record at Streator was kept by the late Dr. E. Evans, of that city.

Record of artesian-well boring at Streator, Ill.

[Altitude of well mouth, about 618 feet above tide.]

	Feet.
Drift	30
Coal Measures	211
Trenton limestone	203
St. Peter sandstone	225
Calciferous limestone	90
Calciferous sandstone	133
White limestone	211
White sandstone	37
Gray limestone	50
Red sandstone	15
Gray limestone	32
White sandstone	168
Blue shale	100
Dark limestone	73
Variable sandstone	187
Soft, white limestone	60
Variable clay shales	158
Red sandstone	80
Blue clay shale	50
Bluish limestone	50
Potsdam sandstone	333
Total	2,496

Record of well boring at Ottawa, Ill., foot of bluff at north end of Lasalle street.

[Altitude of well mouth, 73 feet above Illinois River, or 520 feet above tide.]

	Feet.
Alluvium, etc	35
St. Peter sandstone	130
Mainly limestone	145
Mainly sandstone	110
Fine limestone	175
Hard limestone, with thin sandstone beds and iron pyrites	260
Blue, sandy shale	120

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[1] See discussion by Professor Udden in Chapter X.

	Feet.
Hard sandstone	100
Soft, white sandstone	360
Hard, dark-colored rock	90
Potsdam sandstone, with much water	200
Total	1,840

Record of well boring at Joliet steel mill.

[Altitude of well mouth, about 550 feet above tide.]

	Feet.
Drift	7
Niagara limestone	230
Dark-colored shale (Hudson River)	68
Trenton limestone	334
St. Peter sandstone	217
Red marl	40
Limestone	450
Sharp sandstone	175
Blue shale	50
Shaly limestone	125
Shale	230
Potsdam sandstone, with much water	150
Total	2,076

In the following table are arranged a few of the records of wells in the vicinity of Chicago. They show remarkable variations in the thickness of certain formations within short distances. The most remarkable is the St. Peter, which, in this small district, apparently ranges from 89 feet to 420 feet. The general reliability of the various records seems beyond question, for those which are not given by the drillers were furnished by men who were interested in the geologic structure.

Records of several wells in and around Chicago, showing variation in thickness of formations and elevation of contacts, in feet.

Location.	Distance between adjacent wells.	Elevation of curb.	Top of Niagara.	Thickness of Niagara.	Contact between Niagara and Hudson River shales.	Thickness of Hudson River shales.	Contact between Hudson River shales and Trenton limestone.	Thickness of Trenton.	Contact between Trenton and St. Peter sandstone.	Thickness of St. Peter sandstone.	Contact between St. Peter sandstone and marl or shale.	Thickness of marl or shale.	Contact between shale and Lower Magnesian limestone.	Thickness of limestone, sandstone, etc., below St. Peter sandstone.	Authority.
	Miles.														
Lake Bluff	0	682	475	320	155	198	*43*	216	*259*	167	*426*	32	*458*	46+	Drillers, Gray Bros.
Highland Park	8	695	520	400	120	200	*80*	240	*320*	200	*520*	50	*570*	935+	Driller, John Peterson.
Winnetka	6	658	474	316	158	192	*34*	247	*281*	212	*493*	45	*538*	470+	Drillers, Gray Bros.
South Evanston	7	612	540	260	280	230	50	270	*220*	420	*640*	14	*654*	336+	Dr. Oliver Marcy.
Chicago and Western avenues.	10	612	612	395	217	148	69	157+	......	......	......	....	......	......	W. T. B. Read.
Union Stock Yards	5	595	500±	254	246±	250	4±	325	*329*±	155	*484*	0	*484*±	70+	Dr. H. M. Bannister.
Morgan Park	10	640	477	.....	......	.....	......	......	*405*	.....	.....	....	......	......	W. S. Gamble, C. E.
Hammond	10	600	490	.....	......	.....	......	......	*460*	190	*650*	0	*650*	650+	W. F. Bridge, C. E.
Crown Point[1]	15	736	484	433	51	*234*	*183*	342	*525*	89	*614*	0	*650*	15+	Dr. A. J. Phinney.
Average	......	.....	......	.....	......	207	......	273	......	205	.....	....	......	......	

[1] At Crown Point the shales above the Trenton are separated into two beds, between which is a bed of limestone 57 feet thick, thought by Dr. Phinney to be Clinton limestone. This section also includes Devonian shales, and possibly Devonian limestone. The thickness of the Niagara may, therefore, be less than indicated above.

NOTE.—Italic numerals represent altitudes below sea level.

THE TERTIARY DEPOSITS.

These deposits are found in great thickness in the southern end of the State, and are probably present in many places beneath the drift at points farther north. Prof. R. D. Salisbury has found numerous exposures of beds of gravel and sand of pre-Glacial age on the border of the Mississippi between Alton and Warsaw, thus corroborating Professor Worthen's suspicion of the occurrence of such beds in the vicinity of Warsaw and Quincy, though he has not settled their exact date of deposition, compared with the Tertiary of southern Illinois. The deposits in southern Illinois are thought by Worthen to be of Eocene age.

These deposits consist of a variety of material, a large part of which is sand or gravel, but there are also beds of compact clay. The contained water is found in many places to be strongly chalybeate, and is, on the whole, less agreeable to the taste than water from drift gravel and sand. So far as known to the writer, artesian wells have not been found in these deposits within the State of Illinois. Whether or not the conditions are favorable for their development has not been ascertained.

GEOGRAPHIC DISTRIBUTION OF WELLS.

The artesian wells of Illinois are found mainly in the northern third of the State, on the north and west of the Illinois River. They are somewhat irregularly distributed. In a few sections, such as the city of Chicago, the head-water portions of the Illinois Valley, and the Mississippi Valley, the wells are very abundant, being, indeed, so numerous that the amount of flow is affected. Throughout the greater part of the area, however, they occur only at intervals of several miles. They are found mainly in the large towns of the district, but a few are located in villages, and rarely one has been made on a farm. Attention has already been called to the large use of these wells as sources of city water supply, and they are also used in various manufacturing industries.

The accompanying map (Pl. CXIII) shows the position of the wells, both flowing and nonflowing. It will be observed that the flowing wells are confined largely to the valleys, though a few occur on the lower parts of the upland.

In the central and southern portion of Illinois the occurrence of artesian waters of good quality has not been thoroughly tested. That region being underlain largely by Coal Measures shales, which contain sulphur and various mineral ingredients unpleasant to the taste, it can scarcely be expected that the water will be generally of good quality, suitable for drinking purposes. It has been found, however, that in some places wells with good quality of water may be obtained if certain horizons are selected which are free from these objectionable minerals. It should not, therefore, be understood that these portions of the State are entirely unfavorable for the development of artesian wells. But much discretion will be necessary in separating waters and selecting the proper horizon. In the district outlined as the main artesian-well district no such separation is called for, since the waters are generally wholesome and of agreeable taste.

STRATIGRAPHIC DISTRIBUTION OF WELLS.

Artesian wells have been found in nearly all of the main geological formations, excepting the Hudson River shales and Kinderhook shales. The best horizon is that of the Potsdam sandstone, which occurs at the base of the Paleozoic series. This is a very thick formation, and is usually sufficiently porous to readily transmit water. Mr. Mead estimates that in its most porous portions in Wisconsin it has the capacity to absorb water to an extent of 20 to 40 per cent of its volume. Such porosity is, however, not general, though a large part of the deposit will probably have a capacity equal to several per cent of its volume.

The next in order of importance, and the leading formation in order of development, is the St. Peter sandstone, which is also a very porous rock, well adapted for transmitting water. This deposit is, however, a thin one, averaging scarcely 200 feet, and is in places subject to changes to a shaly condition. Such being the case, wells in northern Illinois have often passed through it into the underlying Potsdam for their supply. As it lies much nearer to the surface than the Potsdam, it is over much of northern and all of western Illinois a more common source of supply for wells than the latter. Probably as many wells are obtained from this one formation as from the Potsdam and all others combined.

Next in order of importance is the portion of the Trenton formation known as the Galena limestone. In its lower portion the Galena limestone frequently becomes a porous, somewhat sandy formation, with a capacity for transmitting water nearly as great as the regular sandstone. It is this porous portion of the Trenton which in Indiana and Ohio is a gas-yielding rock, and where this porous rock is at too low a level to contain gas or oil it is filled with water. It is therefore an extensive water-bearing rock. Unfortunately, it is in Indiana and Ohio a salt water, but in Illinois it is usually suitable for domestic use. Well drillers in Illinois are in the habit of confounding this formation with the St. Peter sandstone, since it lies but a short distance above the latter. It appears not to have a very definite water horizon, for wells in neighboring villages often find the water in it at widely different depths. Though apparently subject to changes in texture at all the water levels, there is probably some connection by which the water may be transmitted readily.

The next formation in order of importance is the somewhat complex series of limestones and sandstones found between the St. Peter and the Potsdam, and called by the rather indefinite name Lower Magnesian limestone. The large amount of sandstone makes this an especially unfortunate name. As already shown, this formation is difficult to separate from the Potsdam, and in many cases it is difficult to say where the border line lies. The decision whether any given well is in the Potsdam or Lower Magnesian sandstones will depend upon the settlement of this border line. In the table of artesian-well data, which appears herewith, wells which have obtained their supply from this part of the rock series are provisionally referred to the Lower Magnesian. The wells are usually found in the sandstone beds, some of which are nearly as porous as the undoubted Potsdam.

The next formation in order of importance is the Niagara limestone. This appears, like the Galena, to be subject in limited areas to a change to a sandy constitution, in which case it often transmits water readily. This limestone also transmits much water through crevices or fissures, and wells are frequently obtained where no change to a sandy constitution has occurred. This formation lies so far above the level of the St. Peter that it should not be confounded with the latter, yet instances have occurred where such seems to have been the case. The water from the Niagara probably has access to many of the deep wells of northeastern Illinois, which are generally supposed to be supplied from lower horizons.

A few wells have been obtained from formations above the Niagara, but such wells are usually of much less strength than those from the main horizons. As already noted, it will be necessary, in the case of the Coal Measures, to separate the waters which are strongly impregnated with objectionable minerals from those having agreeable taste, before successful wells can be obtained.

Reviewing the above statements, it appears that the three main horizons for artesian wells are the Potsdam, the St. Peter, and the Galena. The other horizons are of minor importance, being more or less uncertain sources for wells.

DEPTH OF WELLS.

The artesian wells have a known range in depth of from about 40 feet to 3,115 feet. The shallowest wells are found along the Illinois River Valley, where the St. Peter and the Lower Magnesian strata lie at slight depth. Several hundred wells have been obtained in this valley at depths of 150 to 400 feet. It is estimated that in the city of Ottawa alone there are 200 such wells, and there are nearly as many in the city of Marseilles. Aside from this limited district along the Illinois, it is rare to find strong artesian wells at less than 500 feet, and the depth usually much exceeds that amount. The average depth for the 168 wells given below in the tabulated artesian-well data is 1,377 feet. The expense of sinking a well to a depth of 1,000 or 1,500 feet is usually not more than $3,000, and in the majority of cases the supply of water is such as to abundantly repay the outlay. Wells which have penetrated to a depth of 2,500 or 3,000 feet usually cost $6,000 to $12,000, and unless very strong flows of water of good quality are obtained there is not an adequate return for the investment. It is found, however, that in the city of Chicago, where large quantities of water are in demand, wells may profitably be sunk to a depth of 2,000 feet or more. Wells at various points in the northern part of the State exceed 2,000 feet in depth. On the whole, it may be considered safe to make sufficient outlay in that portion of the State to reach a depth of 2,000 to 2,500 feet, as the wells are generally strong and of good quality. The following list embraces the wells with a depth of 2,000 feet or more in which the returns seem to justify the outlay:

Profitable wells 2,000 feet in depth.

Location.	No.	Depth.
		Feet.
Amboy	1	2, 000
Aurora	2	2, 270 and 2, 255
Chicago	[1] 30	2, 000 to 2, 700
Davenport	3	2, 100
Elgin	2	2, 026 and 2, 230
Harvey	1	2, 075
Joliet Steel Mill	1	2, 076
Mount Carroll	1	2, 502
Oak Park	1	2, 200
Polo	1	2, 098
Princeton	2	2, 092 and 2, 500
Riverside	1	2, 200
Rock Island	1	2, 282

[1] Estimated.

A longer list might be prepared of wells in which it was found not necessary to penetrate to this great depth, because the demand was abundantly supplied at less depth.

TABULATION OF ARTESIAN-WELL DATA.

In the following table the principal facts concerning the wells are presented. These facts were obtained largely by correspondence with the well owners or superintendents, for the writer has not had opportunity to examine many of the wells. Where not obtained directly or in this manner, a considerable part of the information has been gathered from Mr. Daniel W. Mead's tables in his paper on the hydrography of Illinois. The records for wells at Davenport, Rock Island, Moline, and Geneseo were furnished by Prof. J. A. Udden. A few records have been obtained from the Illinois Geological Reports, and a few from other publications.

In most cases the tables indicate precise altitudes and depths. The depth of well and of casing is nearly always based upon careful measurements.

Altitude.—The altitude of the well mouth is in some cases liable to an error of a few feet. This liability to error comes from assuming the well to have the same altitude as the railway station nearest it. In most cases it is known that the error is very slight. When there is a liability to an error of some consequence the sign (±) is affixed.

Capacity.—The capacity of the wells is not satisfactorily determined. In some cases the natural flow has been given, and in others the amount which can be pumped. As the supply can be greatly increased by pumping, the relative natural strength is not shown. The table is of value in showing actual use made of the wells.

Casing.—The water beds indicated in this table are in some instances all used by the well, and in other instances all except the lower are shut off by casing. The amount of casing used will serve to indicate what veins are left available for the wells.

Head.—The head, or rise of water in the wells, is affected by both natural and artificial influences. Neither of these are, as a rule, fully understood; consequently theoretical calculations are very liable to prove incorrect.

Determinations of head which appear in the following table are in some cases precise, while in others they are only approximate. The most precise are those made by Professor Udden from Rock Island and vicinity. Much care was exercised by Professor Udden in determining the elevation of the well mouth, the variations of head in the different wells, and the decrease of head in certain wells. Since these data are very reliable, the variations in head displayed by neighboring wells are of much interest and significance. It is probable that the wells of that district show no greater variation than is liable to appear in any artesian field. They serve to show that neighboring wells may vary a score or more of feet when from the same water horizon, and demonstrate the futility of predicting to a precise foot the height to which water will rise. Similar variations in head are reported by Mr. Mead to occur at Clinton, Iowa.

The head from the different water horizons seems to differ but little in northern and western Illinois, though a slightly greater head is generally found in the Potsdam than in the veins of higher horizons. Under the most favorable conditions the head from the St. Peter and the Galena appears to reach about 675 feet, as is the case at Monmouth, while from the Potsdam it appears to rise slightly above 700 feet, as shown by several wells in western Illinois. Qualifying conditions come in, however, which reduce the available head to the amount of 50 to 75 feet below the levels just given. Few wells in northern Illinois can be depended upon to maintain a head much exceeding 600 feet.

In the portion of the Illinois Valley near the point where the St.

Peter outcrops, the head from that formation is much lower than in surrounding districts, and it is thought that the outcrop of the water-bearing rock has led to this reduction. Data concerning this interesting region are meager, and hence the extent of the influence of this outcrop can not be confidently stated. The formation appears to have much greater extent to the south and east than toward the west. The lowest head is between Utica and Seneca, where it is but about 525 feet above tide. Eastward it reaches only 588 feet at Braidwood; southward, it reaches only 580 feet at Streator; but westward at Princeton, no farther than the points just named, the head is found to be 638 feet, or about as great as in the majority of wells in western Illinois.

In many cases there has been a marked loss of head since a well was made. For this reason it has been found necessary to arrange two columns, one showing the original, the other the present head. There are probably several causes for this loss of head. Among the most prominent, perhaps, is the clogging of the water-bearing stratum at the point where it issues into the well. This, however, has not been tested, so far as the writer is aware. Wells clogged in this way may often have their head restored by the discharge of some explosive, which causes a loosening of the bed at the point of entrance to the well. When a new well is made in the vicinity of one which has lost head and is found to have a head as great as the original head of that well, there is very strong probability that the loss of head is due to the clogging of the water bed or of the pipe. In some cases wells have lost head because of defective casing, there being strata about the well which absorbed water that would otherwise rise above the surface.

In certain districts loss of head has resulted from the overtaxing of the water bed. When several wells are sunk within a small area, as is sometimes the case in the most favorable localities for wells, the head is found to be greatly reduced. One of the best illustrations is afforded by the city of Chicago; and the Chicago district, when thoroughly examined, will probably throw much light upon the effect of overdrawing the natural flow of a well. The original head for the Galena and St. Peter water in the vicinity of Chicago is about 690 feet. At present water can scarcely be made to rise above 600 feet at any point near the city. The great drafts made in Chicago, which amount to several million gallons per day, appear to have reduced the head for several miles to the west and south from the limits of the city—as far west, it is thought, as the Des Plaines River, a distance of 10 miles from the part of the city where the wells are most numerous. Toward the south the head appears to have been lowered to an even greater distance. Another locality where the head appears to have been lowered by heavy pumping is found at Joliet. Mr. F. W. Dewey, the superintendent of waterworks of that city, reports that heavy pumping of a single well has been found to lower the head several feet in wells nearly one-half mile distant. It is probable that the Rock Island district has been affected to some extent by an overtaxing of head, though data are not available on that point.

The drawbacks, both natural and artificial, being so great, it is not at all remarkable that wells are seldom found to reach the theoretical head. Attention has already been called to the effect of an influx of surface water in raising the apparent head of wells which do not overflow. This is thought to be very great in the northeastern part of the State, where the drift beds are heavily charged with water.

Quality of water.—The chemical analyses which have been made, although few and from mixed water veins, are sufficient to throw some light upon the quality of water. They indicate an increasing amount of mineral matter in passing from north to south. This is a feature which is to be expected in passing away from the absorption area, for the strata through which the waters are transmitted contain soluble constituents, and wells which are remote from the absorption area must necessarily furnish waters which have been longer confined in these strata than those near the fountain head, and are in consequence more highly charged with the soluble minerals. The several strata which transmit water vary greatly in the amount of soluble constituents, and it is thought that a separation of the veins from each horizon would show marked variations in a given well. Indeed, certain properties of the water are usually recognized as characteristic of certain horizons. Unfortunately, such separation is rarely made in the waters which have been analyzed.

Of the wells located in the northern tier of counties, waters have been analyzed at Galena and Rockford. The former shows about 12.5 grains of mineral matter per gallon from Potsdam water. The latter shows 28.7 grains from St. Peter and 27.8 grains from Potsdam water. In the second tier of counties waters have been analyzed from several points, and show a range from 17.5 to 91.24 grains, as follows:

Location.	Geological source.	Grains per U. S. gallon.
Winnetka	Unknown	51.60
Evanston	Mainly St. Peter	71.30
Chicago, Munger's laundry	Unknown	23.23
Chicago, Leland Hotel	do	16.99
Chicago, Auditorium Hotel	do	91.24
Oakpark	Mainly Potsdam	56.90
Turner	do	18.20
Elgin	do	18.1
Dekalb	St. Peter, etc	17.5
Dixon waterworks	Potsdam	18.0
Dixon Condensing Co	do	28.39
Sterling	do	30.60

Analyses of waters in the vicinity of Rock Island show the following amounts of mineral matter:

Locality.	Geological source.	Grains per U. S. gallon.
Milan	Galena and St. Peter	68.4
Moline, paper mill	Galena, etc	71.9
East Moline	Galena and St. Peter	70.4
Rock Island, brewery	do	67.3
Davenport, glucose works	Galena and Potsdam	60.2

At Geneseo a well obtaining water from several horizons shows 157.4 grains; at Monmouth a well from St. Peter shows 73.9 grains; at Peru a well, probably from St. Peter, shows 50.9 grains; at Princeton only 28.5 grains are reported. Analyses farther south show a much larger amount than in any of the wells thus far mentioned. Thus, at Lagrange, Mo., 424 grains; at Hannibal, Mo., 987.64 grains; at Barry, Ill., 367 grains; and at St. Louis, Mo., 550.2 grains. At Jerseyville, however, only 141.5 grains are reported.

The most widely prevalent minerals of these waters which have been analyzed—and it is thought that the waters are fairly representative of the region—are calcium and magnesium carbonate and bicarbonate. These are generally present in all wells to such an extent as to render the water somewhat hard for laundry purposes. In many cases, also, wells drilled to supply water for boilers have found water too strongly impregnated by these minerals for satisfactory use.

Sodium chloride occurs only in small amount in the water of the northern part of the State, only a fraction of a grain per gallon being found in the wells at Galena, Rockford, Dekalb, Dixon, and Sterling, and less than 3 grains in the Chicago analyses. Less than 3 grains per gallon are found at Elgin, Aurora, Turner, and Winnetka, but at Oakpark 30.54 grains of potassium and sodium chlorides are reported. In the vicinity of Rock Island the wells are more salt than at Princeton and Monmouth, there being from 27 to 32 grains of sodium chloride found in the several waters analyzed, while at Princeton but 3.7 grains and at Monmouth but 9.61 grains are reported. Upon passing south to the wells containing large mineral residue, we find that sodium chloride greatly preponderates. Thus, at Lagrange, Mo., 320.6 grains; at Hannibal, Mo., 712.28 grains; at Barry, Ill., 277.7 grains, and at St. Louis, Mo., 401.5 grains are reported. At Jerseyville, where a smaller mineral residue occurs, there are 85.9 grains of sodium chloride. The salinity is such even at Rock Island as to be objectionable until a taste for the water has been acquired, while at points where the sodium chloride is greater the use of the water for drinking purposes can scarcely become popular.

In several cases wells are found to contain sulphates of various kinds in measurable amount, as may be seen by the analyses. Sodium sulphate is usually present with the sodium chloride in greater or less amount, and tends to render the water disagreeable.

Hydrogen sulphide is usually abundant in waters from the Niagara and from the Galena, but is less conspicuous in the St. Peter waters, and, so far as known, is not abundant at lower horizons.

Iron salts are not usually present in sufficient amount to greatly affect the water.

Where no analyses have been made statements concerning the quality of the water have been furnished by the well owners or superintendents. These are presented in the table, since they serve to show the popular idea of the quality of the water.

Tabulated artesian-well data.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Aledo, waterworks	1890	738	3,115	(?)	2,910	(?)	Drift, 41-60 ft.: St. Peter (?), 1,200 ft.; Potsdam, 2,300, 2,620, and 3,071 ft.	663	708	First veins fresh: brackish at 2,300 ft.		
Algonquin, Ill., Condensing Co.		760	2,527	(?)	(?)	(?)	Probably Potsdam	(?)	(?)	Rusts pipes; use discontinued.		
Amboy, waterworks		778	2,000	(?)	(?)	(?)	St. Peter (?), 390 ft.; Potsdam, 1,100 and 1,700 ft.	781		Pleasant and pure	$5,500	
Aurora, waterworks, No. 1		650±	1,388	8-6	(?)	350	St. Peter	(?)	(?)	See analysis	4,078	
Aurora, waterworks, No. 2		650±	2,270	(?)	(?)	(?)	Potsdam	710	740 ?	do		
Aurora, waterworks, No. 3		650±	2,255	(?)	(?)	(?)	do	710	(?)	do		
Aurora, C., B. & Q. R. R		650	663	(?)	(?)	(?)	St. Peter	(?)	(?)	(?)		
Austin, town well		617	1,205	(?)	(?)	(?)	do	(?)	(?)			
Barry, waterworks	1880	760	2,510	6	60	100+	Fresh water at 60 ft.; St. Peter (?), 1,150 ft.	625	625	See analysis	6,000	$1,000
Beardstown, private well		445	1,100			175	Devonian, 350 ft.; flow with gas and oil, 500-600 ft.			do		
Belvidere, waterworks	1889	763	1,950	8-4	58	400	St. Peter and Potsdam	757		do	4,525	1,000
Belleville, brewery		540	503				Base of Coal Measures	460		Slightly saline		
Braidwood, test boring	1888	588	900	4	80		St Peter, 655 ft.	588		Slightly sulphurous	3,000	
Canton, waterworks, No. 1	1882	661	2,500	4	90	125	Lower Magnesian (?), 2,050 ft.	630		Pure "magnesia" water.	8,000	3,000
Canton, waterworks, No. 2	1895	600	1,646½	14-6	797	260	Galena, 1,100-1,305 ft.; St. Peter, 1,405-1,646½ ft.	615		Pure and pleasant	4,271	4,733
Carrollton, waterworks		615±	1,330				St. Peter, 1,225-1,330 ft.	565				
Carbon Cliff, Argillo works	1890	592	915	5½	300	400	Galena, 850 ft.	642+	675	Brackish		
Carthage, No. 1		678	1,800	5-3			Niagara 750±; St. Peter, 1,000± ft.	662		do		
Carthage, No. 2	1892	678	1,000	10-8	223		Galena, 865 ft; St. Peter, 975 ft.	658		do	1,500	

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Chicago, No. 1	1864	613	711	4¼		400	Galena (?), 711 ft.	600±	690	Hard, but pleasant		
Chicago, No. 2	1865	613	694	5			Galena (?), 694 ft.	600±	690	do		
Chicago, stock yards, No. 1	1866	590±	1,200				St. Peter	590		do		
Chicago, Lehman well		595	2,604				Potsdam			Brackish		
Chicago, Swift & Co		595	2,700				do					
Clinton, Iowa, waterworks		590	1,035	5				658		See analysis		
Do		590	1,674	8–5		1,500	Potsdam	635				
Clinton, Iowa, Paper Co		590	1,065	5½				625				
Collinsville, waterworks	1893	465	573				Sandstone, 509–573 ft.	345		"Like appollinaris"	1,300±	
Columbia, test boring	1886	528	1,010	5⅝			Sandstone, 1,000 ft.	518		Not pleasant	1,750	
Coulterville, test boring		545	1,117				Chester sandstone			Brackish		
Danville Junction, test boring.		610	2,008				Sandstone, 1,700–1,735 ft.			do		
Davenport, Iowa, Packing Co.	1893	564	1,180	5		250			609			
Davenport, Iowa, glucose factory, No. 1.	1880		1,500	5	8	200	St. Peter, 970–1,040 ft.		618	See analysis		
Davenport, Iowa, glucose factory, Nos. 2, 3, 4.	(?)		2,100	5	80	400						
	1888		2,100	5	80	400	St. Peter, 970–1,040 ft.					
	1892		2,100	5	80	400	Potsdam, 1,870–2,100 ft.		641			
Davenport, Iowa, Kimball House.	1890	579	1,080±	5	800	120	Galena, 740 ft.; St. Peter, 1,075 ft.	599	637	Sulphurous and salt at 740 ft.; less sulphurous and salt at 1,075 ft.		
Davenport, Iowa, ice factory	1893	590	1,064	(?)	(?)	240	Galena, 775 ft.; St. Peter, at bottom.	600	(?)			
Davenport, Iowa, woolen mill.	1890	564	1,053	3½	700	300	Magnesian, 85 ft.; Galena, 700 ft; St. Peter, 1,050 ft.	599+	590	Sulphurous at 700 ft.		

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Davenport, Iowa, malt and grain.	1892	592	1,076	5	1,050	300	Galena, 700 ft.; St. Peter, 1,050-1,076 ft.	605±	612+	Sulphurous at 700 ft.; pure at 1,050-1,076 ft.	....	....
Davenport, Iowa, Schmidt Building.	1892	576	1,200	4	1,200	73	Galena (?); St. Peter, near bottom.	(?)	600±	Not used	....	....
Davenport, Iowa, Gas Co., Nos. 1, 2.	1891	564	1,200	5-4	1,200	400?	St. Peter, near bottom	611	611	....	....	....
Davenport, Iowa, bottling works.	1891	575	780	(?)	(?)	300±	Galena, 750± ft.	634	657	Used for carbonated waters.	....	....
Dekalb, public square	1882	897	800	8-6	200	(?)	St. Peter and drift	772	772	See analysis	$4,000	$7,070
Dekalb, in city	1880	887	981	6-4	190	(?)	.....do	827	827	Pure	....	....
Do	1891	883	700	(?)	(?)	(?)	.....do	843	843	....	....	....
DeKalb, block 18	1892	899	880	10-8	(?)	(?)	.....do	844	844	....	....	....
DeKalb, waterworks	1895	855	890	14-6	(?)	300	Drift, 125-161 ft.; St. Peter, 595-890 ft.	790	790	Pure and pleasant	....	....
Near Denver, Hancock County.	....	700	1,030	....	....	....	St. Peter	660	660	.....do	....	....
Dixon, Nos. 1, 2, 3 (waterworks).	....	675±	1,640 1,730 1,810	....	....	....	Potsdam	(?)	(?)	See analysis	....	....
East Dubuque, town well	....	612	940	5	....	420	.....do	707?	....	Pleasant	....	....
East Peoria, test boring	....	450±	734	....	....	....	317 and 734 ft	....	....	Brackish	....	....
Elgin, watch factory	....	715	2,026	6	52	....	St. Peter, 650-700 ft; Potsdam, 2,024 ft.	....	742	Sulphurous at 650-700 ft.; soft at 2024 ft.	....	....
Elgin, Insane Hospital	....	735	2,230	....	....	....	St. Peter, 650-700 ft.; Potsdam, 2,000± ft.	731	....	St. Peter, sulphurous; see analysis.	....	....
Elgin, Creamery Co	1894	722	1,400	....	....	....	Galena, 487-514 ft.; sandstone at 972, 1,208, and 1,398 ft.	716	....	Sulphurous, 650-700 ft	....	....
Elgin, Condensing Co	1876	712	1,876	....	....	....	St. Peter, 650-700 ft	714	740	.....do	....	....

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Equality, salt well:	1	375 ±	1,800	6–3½	400	....	Probably Chester, 900 ft.	....	....	Very salt	....	....
Evanston, city well	....	612	1,602	....	....	....	Limestone, 562-832 ft	617	....	See analysis	....	....
Fairbury, waterworks	1892	708	2,002	8	2,002	....	First water at 60 ft.; deeper veins struck.	648	....	Soft and pleasant	$4,500	$2,000
Forreston, waterworks	1894	927	300	8	40	....	....	907	....	....	400	1,000
Fort Madison, Iowa, paper mill.	....	522	687	....	....	....	Probably Niagara at 610–687 ft.	....	648	Sulphurous	....	....
Fulton, waterworks	....	594	1,246	5	....	300	First flow at 475 ft.; Potsdam at 940–1,050 ft.	655	....	Sulphurous at 475 ft.	....	....
Galena, waterworks	....	605 ±	1,209	8	....	166	Potsdam	690	....	See analysis	....	....
Galesburg, waterworks	1896	737	1,226	14–6	1,060	120	St. Peter, 1,060–1,226 ft.	....	635	Pleasant and pure	4,000	....
Geneseo, waterworks	....	645 ±	2,250	6	....	190	Devonian or Niagara at 140–160 ft.; Galena at 950–975 ft.; Lower Magnesian at 1,350, 1,450, and 1,590 ft.; Potsdam, 2,040–2,160 ft.	....	676	....do	....	....
Hamilton, sanitarium	....	600 ±	680	....	....	36	Niagara	663	....	Sulphurous	....	....
Harvey, waterworks	....	603	{ 1,300 2,075 }	....	....	250	St. Peter and Potsdam	593	....	....	....	....
Harvard, railroad well	1892	935	900	12–7	102	90	....	894	....	Hard, with magnesia	7,000	2,000
Hennepin, town well	1875	495	800	4	800	80	....	545	....	Slightly saline	....	....
Henry, town well	....	490	1,355	3½	....	32	....	....	....	White sulphur	....	....
Highland Park, city well	1887	685	2,200	8–5	160	150	Galena, 900 ft.; Lower Magnesian, 1,300 ft.; Potsdam, 1,700–2,200 ft.	....	694+	Slightly saline and hard.	3,200	....
Hinsdale, waterworks	....	691	864	....	....	....	....	....	....	....	....	....
Ipava, waterworks	....	650	1,570	4	....	60	Galena (?), 1,010 ft.; St. Peter, depth (?).	....	....	Salt and sulphur at 1,010 ft.; lower vein pleasant.	....	....

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Jacksonville, J. Clapp & Sons	1887	570	2,408	5⅝	....	85	Lower Magnesian (?), 2,100 ft.	580	....	Brackish	....	....
Jacksonville, city well	1888	570	2,343	6–4⅝	1,950	30	Lower Magnesian (?), 2,340 ft.	555	....	do	....	....
Jacksonville, waterworks	1895	570	3,028	6⅝–5⅝	1,800	500	St. Peter (?), 1,800 ft.; Potsdam, 3,000 ft.	540	540	Slightly saline	$12,500	....
Jerseyville, waterworks	....	662	2,003	12–3	(?)	200	St. Peter, 1,400–1,600 ft	562	....	See analysis	....	....
Joliet, steel mill	....	550	2,076	....	....	(?)	Potsdam	560	....	(?)	....	....
Joliet, waterworks, No. 1	....	535	1,200	....	....	500	St. Peter	....	....	(?)	....	....
Joliet, waterworks, No. 2	....	535	1,700	....	....	500	Lower Magnesian (?)	545	575	See analysis	....	....
Kankakee, private well	....	620	1,000	4	(?)	(?)	St. Peter, 900 ft	605	....	(?)	....	....
Keokuk, Iowa, Rand Park	....	637	1,987	6–4	1,975	(?)	Niagara at 600 ft.; Galena or Trenton at 900 ft.; flow near bottom Lower Magnesian (?).	637	....	Upper flows sulphurous; lower flows saline.	4,500	Siphon, $25.
Kewanee, No. 1	....	847	1,480	9–6	(?)	130	Probably St. Peter, 1,000 ft.	....	697	Soft and pleasant	....	....
Kewanee, No. 2	....	847	1,050	7–4	(?)	80	do	....	....	do	....	....
Kewanee, No. 3	....	847	1,050	6–4	(?)	52	do	....	....	do	....	....
Knoxville, waterworks	1896	770	1,350	8	1,180	80	St. Peter, 1,180–1,350 ft	....	....	Pleasant and pure	....	....
Lagrange, Mo., Wyaconda well.	....	490	840	....	....	60	Probably St. Peter	....	(?)	Brackish; see analysis.	....	....
Lake Forest, C. B. Farwell	....	650±	960	(?)	(?)	60	do	....	700	(?)	....	....
Lasalle, waterworks, No. 1	1895	460	332	6	(?)	150	Coal Measures at 250 ft.	....	....	Moderately soft	581.00	....
Lasalle, waterworks, No. 2	1895		502	6		200					878.50	....
Lemont, waterworks	....	596±	1,366	....	....	(?)	Probably St. Peter	....	656	(?)	....	....
Lodi, Ind., artesian well	1865	510	1,155	....	....	35	Base of Devonian, 1,051 ft	....	(?)	Brackish; NaCl, 502 grains per United States gallon.	....	....
Macomb, waterworks	....	700	1,630	....	1,135	(?)	St. Peter, 1,135–1,360 ft	....	....	See analysis	....	....

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Marseilles, private wells...	...	480 ±	100–200	3–2	...	12	St. Peter...	492	500 ±	Pleasant and pure...	...	...
Mendota, waterworks...	...	747	400	...	...	...	St. Peter, 350–400 ft...	700	700	...do...	...	...
Milan, town well...	1894	566	1, 157	5	16	318	Galena, 800 ft.; St. Peter, 1,000 ft.	634	634	See analysis...	...	...
Millstadt, test boring...	1895	625 ±	620	$7\frac{5}{8}$	200	4	Limestone...	550	...	Hard...	$1, 200	$800
Minonk, waterworks...	1893	749	1, 755	10–6	700	100	Subcarboniferous limestone, 750 ft.; St. Peter (?), 1,700 ± ft.	600	600	Moderately hard...	5, 000	1, 500
Minooka, test boring...	...	614	2, 100	...	...	...	Potsdam, 1,985 ft...	...	660	...	...	...
Moline (East Moline)...	1895	579	1, 340	6	28	240	Galena, about 750 ft.; St. Peter, 1,030–1,080 ft.	615	615	See analysis...	...	...
Moline, paper mill...	1881	564	1, 628	5	...	350	Galena, about 700 ft.; lower veins; depth ?	...	646	...do...	...	...
Moline, Prospect Park...	1891	611	1, 166	...	76	250 ±	...	...	636	...	...	...
Monmouth, waterworks, No. 1.	...	735	1, 230	6–4	1, 074	200	St. Peter, 1,074–1,230 ft...	675	...	See analysis...	...	...
Monmouth, waterworks, No. 2.	...	735	1, 227	...	935	...	Galena, 935 ft.; St. Peter, 1,074–1,227 ft.	675	...	...	...	...
Montezuma, Ind...	1891	500 ±	1, 675	4	128	...	Veins at 450 ft., and at 1,100–1,200 ft.	...	500 ±	See analysis...	...	...
Morgan Park, waterworks...	...	640	1, 046	...	...	...	St. Peter, 1,040 ft...	...	595	...	...	...
Morris, waterworks...	...	510 ±	600	...	...	...	St. Peter...	...	...	Moderately hard...	...	...
Mount Carroll, waterworks..	1895	720	2, 502	5	...	...	Potsdam, strong, 1,200 ft.; Potsdam, weaker, 1,300–2,500 ft.	...	...	...	...	...
Oakpark, waterworks, No. 1..	1894	630	1, 568	$6\frac{1}{2}$	65	500	Lower Magnesian (?), 1,529 ft.	610 ±	...	See analysis...	3, 000	1, 000
Oakpark, waterworks, No. 2..	1894	630	2, 200	...	...	...	Lower Magnesian (?), 1,600 ft.; Potsdam, 2,200 ft.	610 ±	...	...	...	...

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Olney		475	2,000				Does not flow			Not used; saline		
Ottawa, Lasalle street		528	1,840				Potsdam, 1,640-1,840 ft		705			
Ottawa, many wells		500±	400				Lower Magnesian, 290-400 ft			Variable; sulphurous		
Palatine, C. & NW. R. R.		748	1,656				Drift, 160 ft.; St. Peter, 800 ft.	750		Pleasant and pure		
Pana, test boring		695	2,507				Weak vein, depth (?)			Brackish		
Park Ridge, waterworks		660	1,500	6-3½				650				
Pedicord, near Marseilles		700±	2,189			8	Potsdam, 1,845-2,143 ft.		700±			
Pekin, City Park		525	850							Salt at 500 ft.		
Peru, waterworks		475±	1,250	6		450	Trenton, near bottom	560		See analysis		
Peru, zinc works		450	1,360	8	1,050	200	Niagara(?).750 ft.; St. Peter, 1,350-1,360 ft.	570				
Polo, waterworks		841	2,098				Potsdam			Pleasant and pure		
Princeton, waterworks, No. 1.	1890	710	2,500				St. Peter and Lower Magnesian.	638		See analysis		
Princeton, waterworks, No. 2.	1894	710	2,092	9⅝-4⅝	1,000	320	St. Peter, 1,521-1,670 ft.; Lower Magnesian (?), 1,850-1,975 ft.	638		Hard; slightly saline.	$7,000	
Red Bud, glucose factory	1887	420	580	3		4	Chester, 200-260 ft.	427		Slightly alkaline	1,500	
Red Bud, test boring	1890	450±	1,350	4			Chester, 230-290 ft.	430±		do		
Riverside, waterworks		617	1,300 2,200	3½		1,000	St. Peter and Potsdam	597		More soda salts than lime.		
Rockford, waterworks, 5 wells.		711	1,300 to 1,996	8-6	400	116-260	St. Peter, 380-400 ft.; Potsdam, 1,200-1,300 ft.		719	See analysis	2,638 to 4,257	
Rock Island, Atlantic Brewery.	1890	577	1,150±	4½		400	Galena, 750 ft.; St. Peter, 980 ft.		647	Sulphurous at 750 ft.; less sulphurous at 980 ft.		

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Rock Island, Mitchell & Lynde Building.	1890 1893	558	2.282	8–4⅝	950±		Devonian weak, 40 ft.; Galena strong, 800 ft.; also from St. Peter, Lower Magnesian, and Potsdam strata.	608	644	Sulphurous at 800 ft.; less sulphurous in lower veins.		
Rushville, waterworks		677	2,500				(?)			Said to have an unpleasant taste.		
Sabula, Iowa, waterworks	1895	592	973		6	720	Limestone vein at 870–973 ft.	670	670	Pleasant and pure		
Savanna, waterworks		592	1,432			500	Potsdam	675		do		
Seneca, several wells	1885	510±	350 630	4			St. Peter, 350± ft.; lower magnesian, 380 ft.	525		Hard and sulphurous	$700 to 1,400	
Shawneetown, oil well		350	1,513				Coal Measures, 730–780 ft.; Carboniferous conglomerates, 1,110–1,300, 1,325–1,370 ft.			Very salt		
Sparta, town well		525	480				Chester, 480 ft	450	450	Soft, not pleasant		
Steelville, Jenkins well	1887	449±	312	2			Coal Measures, depth (?)		450+	Soft, pleasant	300	
Sterling, waterworks		667±	1,450			350	Potsdam		667+	See analysis		
Streator, city well		618	2,496				St. Peter, 450 ft.; Lower Magnesian, depth (?); Potsdam, 2,170–2,496 ft.		578 584 663			
Texas City, gas well		375	302	3½			Coal Measures, gas at 240 ft.		368			
Tuscola, town well		660	792				Sub-Carboniferous limestone (?)					
Utica, several wells		480	40–80	2			St. Peter or Lower Magnesian, 40–80 ft.		485	Pure and pleasant		
Utica, town well		480	290			140	Lower Magnesian (?), 150–290 ft.	525	525	do		

Tabulated artesian-well data—Continued.

Locality and owner.	When made.	Altitude.	Depth.	Diameter.	Amount of casing.	Capacity per minute.	Water bed and veins.	Present head.	Original head.	Quality of water.	Cost.	
											Well.	Pumps, etc.
		Feet.	*Feet.*	*Inches.*	*Feet.*	*Gallons.*						
Utica, James Clark		480	328			280	Lower Magnesian (?), 150–328 ft.	525	525	Pure and pleasant		
Utica, Jacob Norton		480	200 ±				Lower Magnesian (?), 260–300 ft.	525	525	do		
Vermillionville, oil boring			1,000				St. Peter, depth (?); Lower Magnesian, depth (?).			do		
Vermont, test boring		690	2,487				Potsdam (?)			Not in use		
Virginia, test boring		620	750				Sub-Carboniferous (?), 730–750 ft.			Unfit for drinking		
Warsaw, town well	1886	555	860	6	100	200	Galena or Trenton	617	653	Sulphurous	$2,150	
Warsaw, Colonel Marsh's well.	1888	600	800	4		95	do	(?)	650	do		
Warsaw, Negel well	1886	585	780	4		90	do	(?)	650	do	1,950	
Warsaw, William Hill's well.	1887	585	790	4		100	do		650	do		
Warsaw, woolen mill	1891	495	750	6		90			650	do		
Waukegan, old waterworks		600	1,135 1,600 2,005				St. Peter and Lower Magnesian. (?)			Pure, with some iron; sulphurous (?). Not in use.		
Wenona, waterworks		690	1,854			100	Potsdam	565	565	Soft, pleasant		
Wilmington, private wells	1889	540 ±	635	4½	200		St. Peter, 400–635 ft		586	Sulphur and magnesia.	1,500	
Winchester, at mill		545	412				Sub-Carboniferous (?), 350 ft.	470	470	Pleasant and pure		
Winnetka, Lloyd's well		658	1,570			150		650	676	See analysis		
Woodstock, waterworks		916	1,014			500	Probably St. Peter			Soft and pleasant		

CHAPTER IX.

WATER ANALYSES.

The State Board of Health, in 1888 and 1889, made sanitary analyses of the waters used by the State institutions, and also of waters from several cities. In most cases several analyses of a water were made, in order to determine its average condition. In the following table only the averages are presented.[1]

This table is followed by analyses of the polluted waters of the Des Plaines and Illinois rivers and of the canal waters near Chicago, also made by the State Board of Health in 1888 and 1889. With these analyses appear analyses of waters from Lake Michigan and Dupage and Kankakee rivers, which are comparatively unpolluted.

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[1] The full report of analyses will be found in the Preliminary Report to the Illinois State Board of Health on Water Supplies of Illinois and the Pollution of its Streams, by J. H. Rauch, M. D., secretary. Published at Springfield, Ill., 1889.

Waters used by cities and State institutions.

[Analyses mainly by State Board of Health.]

Cities and State institutions.	Season.	Number of analyses.	Total solids. (1)	Suspended matter.	Nitrogen in nitrates.	Chlorine.	Hardness, $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oxygen consumed.	Sulphates.
Alton, Mississippi River	Autumn	15	278. 6	75. 2	....	4. 08	169. 4	. 16	. 35	7. 35	....
Alton, hydrant	do	15	238. 3	33. 3	....	4. 20	174. 0	. 06	. 26	6. 43	....
Anna, Insane Asylum, storage reservoir	do	3	177. 1	2. 4	....	4. 87	131. 0	. 16	. 13	2. 45	....
Aurora, artesian well No. 1, 1,388 feet	(?)	1	380. 0	....	. 20	4. 77	....	. 81	. 07	1. 20	....
Aurora, artesian well No. 2, 2,270 feet	(?)	1	500. 8	....	....	124. 0	....	. 37	0	2. 7	....
Aurora, artesian well No. 3, 2,255 feet	(?)	1	445. 8	....	....	85. 0	....	. 28	0	. 40	....
Aurora, Fox River	Autumn	4	302. 5	3. 4	....	2. 44	261. 0	. 06	. 18	3. 98	....
Belleville, Richland Creek, new reservoir	Oct. 10, 1888	1	136. 0	19. 4	....	4. 24	80. 0	. 07	. 51	7. 60	....
Bloomington, shallow drift well	Autumn	4	603. 6	3. 5	....	4. 24	489. 0	. 93	. 08	1. 82	....
Cairo, Ohio River	do	3	208. 4	116. 9	....	3. 10	46. 0	. 08	. 18	4. 53	....
Chandlerville, Sangamon River	Summer	8	317. 8	70. 7	. 75	3. 60	212. 0	. 05	. 28	5. 48	....
Chester, State penitentiary, Mississippi River	Autumn	3	439. 3	111. 2	....	7. 16	. 29	. 07	. 23	5. 52	....
Chicago, Lake Michigan	Summer	27	149. 9	13. 5	....	2. 11	125. 3	. 007	. 08	1. 42	....
Dwight, drift well	do	1	....	....	. 82	....	....	2. 50	. 13	5. 80	....
Decatur, Sangamon River (hydrant)	Autumn	1	364. 3	5. 0	....	6. 01	320. 0	. 05	. 19	3. 04	....
East St. Louis, Mississippi River (pump house)	do	8	616. 4	67. 7	....	4. 45	. 13	. 05	. 41	3. 75	....
Elgin, Insane Asylum, springs	do	3	351. 4	4. 9	....	3. 46	300. 0	. 02	. 05	. 93	....
Elgin, Fox River	do	3	266. 5	2. 0	....	3. 23	282. 0	. 26	. 27	4. 0	....
Freeport, drift wells	do	4	475. 5	1. 7	6. 26	12. 89	435. 0	. 03	. 06	2. 86	....
Galesburg, drift well	do	4	399. 3	11. 3	....	1. 18	370. 0	. 93	. 11	2. 40	....
Galena, artesian well, 1,507 feet	do	4	286. 1	2. 6	....	. 60	201. 0	. 07	. 06	2. 14	....
Jacksonville, storage reservoir, city	Oct. 26, 1888	1	197. 0	2. 1	....	5. 51	160. 0	. 12	. 42	6. 80	....
Jacksonville, artesian well, 2,400 feet, city	Oct. 29, 1888	1	2, 522. 2	1. 1	....	934. 5	460. 0	1. 22	. 01	2. 80	....
Jacksonville, abandoned coal shaft, 210 feet, city	Oct. 30, 1888	1	1, 191. 6	52. 4	....	169. 9	436. 0	2. 50	. 29	6. 56	....
Jacksonville, Insane Asylum, city water	Autumn	3	197. 1	12. 1	....	3. 10	158. 0	. 33	. 36	5. 02	....

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[1] The quantities given in this table indicate the number of grains in one United States gallon.

Waters used by cities and State institutions—Continued.

Cities and State institutions.	Season.	Number of analyses.	Total solids. [1]	Suspended matter.	Nitrogen in nitrates.	Chlorine.	Hardness $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oyxgen consumed.	Sulphates.
Jacksonville, Deaf and Dumb Asylum, city water (filtered).	Autumn....	2	206.4	27.5	....	3.54	147.0	.03	.38	5.80	....
Joliet, artesian well, 1,200 feet, city water..............	Summer....	4	453.1	7.4	.54	8.33	326.6	.03	.08	2.37	....
Joliet, State Penitentiary, artesian wells..... {553 1,948 ft.	Autumn....	3	766.9	1.76	....	199.8	242.0	5.61	.52	2.56	....
Kankakee, Insane Asylum, filter gallery..............	.....do......	5	256.1	15.2	....	2.06	223.0	.03	.26	7.68	....
Lasalle, Little Vermilion River..........................	Summer....	7	375.1	30.8	.36	5.66	210.2	.18	.41	7.15	....
Lincoln, Asylum for Feeble-Minded....................	Autumn....	3	325.9	10.9	....	4.94	285.0	.01	.06	2.53	....
Morrison, storage reservoir................................	.....do......	4	390.4	3.0	6.42	7.48	348.5	.009	.03	1.10	....
Normal, Soldiers' Orphans' Home......................	Winter.....	3	420.2	13.8	2.18	2.22	....	1.06	.11	2.61	....
Ottawa, Fox River..	Summer....	18	330.3	46.3	.02	4.97	242.1	.27	.46	7.06	....
Pekin, drift well..	.....do......	4	341.8	6.5	3.83	2.85	277.8	.009	.038	.59	....
Polo, artesian well...	....	(?)	....	(?)	2.00	7.0	....	.025	.07	....	....
Pontiac, Reform School......................................	Autumn....	3	1,673.7	10.6	....	520.0	522.0	.25	.07	2.10	....
Quincy, Mississippi River...................................	.....do......	2	180.3	12.3	....	1.04	147.0	.07	.27	6.09	....
Rock Island, Mississippi River............................	.....do......	4	192.2	26.2	....	1.31	151.0	.05	.25	6.06	....
Springfield, Sangamon River (pump house)..........	.....do......	2	363.2	23.4	....	3.94	295.0	.408	.084	1.80	....
Streator (R. O. Graham, analyst)......................	(?)	....	424.5	....	.006	4.0	....	.025	.05	....	15.80
Wilmington, Kankakee River..............................	Summer....	19	251.4	35.6	.09	1.01	164.1	.11	.58	12.66	....

[1] The quantities given in this table indicate the number of grains in one United States gallon.

Waters of the Des Plaines and Illinois and tributaries.

[Analyses by State Board of Health in 1888 and 1889.]

Locality.	Season.	Number of analyses.	Total solids. (1)	Suspended matter.	Nitrogen in nitrates.	Chlorine.	Hardness, $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oxygen consumed.
Chicago, Lake Michigan		27	149.9	13.5	0	2.11	125.3	.007	.089	1.42
Bridgeport, canal, Chicago sewerage	Summer	29	471.2	129.2	0	46.81	201.3	12.25	2.55	23.11
Do	Winter	9	376.6	27.2	0	62.93	....	8.92	2.80	26.50
Lockport, canal, Chicago sewerage	Summer	24	431.2	69.8	0	46.12	207.7	10.88	1.99	16.23
Do	Winter	8	408.6	24.6	0	56.08	....	8.14	2.48	22.82
Joliet, Dam 2, canal and Des Plaines water	Summer	26	442.7	107.9	0	43.65	216.8	8.93	1.68	14.30
Do	Winter	8	432.8	55.5	0	57.71	....	8.48	2.66	21.71
Channahon, Dupage River	Summer	21	294.7	14.1	.30	5.78	244.8	.41	.34	4.74
Wilmington, Kankakee River	do	19	251.4	35.6	.09	1.01	164.1	.11	.58	12.66
Morris, Illinois River	do	24	355.9	30.85	.36	32.14	214.8	4.10	.70	10.92
Do	Winter	8	325.2	29.1	0	28.74	....	4.71	1.58	10.69
Lasalle, Illinois River	Summer	23	345.7	50.3	1.03	19.71	211.7	.62	.52	8.55
Do	Winter	9	417.6	93.8	.94	13.10	....	1.45	.63	8.58
Henry, Illinois River	Summer	19	306	27.5	.68	17.66	204.4	.46	.48	8.65
Do	Winter	5	316	30.9	.96	11.69	....	1.05	.40	8.63
Peoria, Illinois River at inlet to pumps	Summer	19	329.75	54.27	.89	12.35	199.7	.21	.52	9.76
Peoria, from hydrant	do	14	327.7	27.4	.89	28.33	206.6	.08	.39	8.18
Pekin, Illinois River	do	16	353	84.3	.79	16.15	204.6	.64	.65	9.41
Do	Winter	6	352	43.5	1.25	11.79	....	1.59	1.01	13.35
Havana, Illinois River	Summer	24	301.78	45.4	.73	11.58	204.2	.34	.43	8.14
Do	Winter	9	352.4	80.8	.41	9.27	....	1.07	.58	9.23
Beardstown, Illinois River	Summer	24	390	84.7	.62	7.52	204.9	.20	.38	7.35
Do	Winter	6	317.8	56.3	.96	6.93	....	.76	.35	5.50
Chicago and Alton Railroad Bridge, Illinois River	Summer	16	402.5	172.5	.71	8.71	213.4	.06	.42	7.65
Grafton, mouth of Illinois	do	12	301.6	50.3	.58	9.20	242.4	.09	.48	7.30
Do	Winter	9	410.8	44.6	.08	23.64	....	.87	.72	9.81

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[1] The quantities given in this table indicate the number of grains in one United States gallon.

The following table of chemical analyses of springs, shallow wells, etc., has been taken in the main from Mr. Mead's report. The additional analyses were obtained through schedules for city water supply. The analyses vary quite widely in the determinations made, some being less complete than may be shown in this table, while a few embrace several not included in the table. Mention of the additional substances is therefore made at this point. In the Bushnell well there is in the analysis a statement that 3.50 grains of alkali occur. In four instances determinations of magnesium sulphate were made, as follows: Dwight, 13.61; Nashville Spring, 103.7; Spring Valley (spring No. 1), 9.12; and Waukesha Hygeia Spring, 4.35 grains. The iron and alumina are not separated in the Lincoln and the Hygeia analyses. At Oregon a small amount (6.90 gr.) of potassium carbonate is reported. At the Perry Iron Spring a large amount of ferrous sulphate (69.96 gr.) is reported. At Spring Valley calcium and magnesium chlorides appear in greater amount than in most waters of the region, there being 33.72 grains. At the Hygeia Spring several additional determinations were made, viz: Free carbonic acid, 1.43 grains; magnesium sulphate, 4.35 grains; magnesium chloride, 0.21 grain; magnesium nitrate, 1.62 grains; iron phosphate, 0.008 grain; iron carbonate with alumina, 3.039 grains.

Chemical analyses of springs, shallow wells, etc.

[Grains per United States gallon.]

Locality.	Calcium carbonate.	Calcium bicarbonate.	Calcium sulphate.	Ferrous carbonate and bicarbonate.	Magnesium carbonate.	Magnesium bicarbonate.	Potassium chloride.	Potassium sulphate.	Silica.	Sodium carbonate.	Sodium bicarbonate.	Sodium chloride.	Sodium sulphate.	Alumina.	Total.	Analyst.
Alcyone Spring (Cook County)	......	18.69	......	......	......	13.79	......	4.86	.68	......	......	......	3.39	1.99	48.08	J. V. Z. Blaney.
Bluemound, waterworks well.	+Mg. 6.76	......	+Mg. 15.66	......	......	......	......	......	......	......	......	13.21	......	......	50.90	W. J. Williams.
Bushnell railroad well, alkali not separated.	7.04	......	.24	......	2.71	......	......	......	.43	......	......	......	......	.13	15.30	George H. Ellis.
Dekalb, Corkin's well in drift.	16.66	......	7.39	.12	6.29	12.25	2.33	......	.87	......	......	......	$+K_2SO_4$ 4.68	......	47.59	G. M. Davidson.
Dwight, waterworks well in drift.	15.65	......	3.83	......	......	......	......	......	.02	......	......	4.41	23.9	+Fe. .36	64.40	Arthur Palmer.
Elgin, Zonian Spring	9.56	......	......	.49	2.49	......	......	......	......	......	.45	.70	1.74	$+SiO_2$ .26	15.74	J. E. Siebel.
Galesburg, old waterworks well.	9.69	......	.33	3.79	5.06	......	.43	......	1.12	......	1.50	.12	......	......	22.06	J. H. Long.
Glen Flora Spring (Cook County).	......	15.57	......	.11	......	11.09	......	......	.91	......	6.45	.18	1.85	.15	36.41	J. V. Z. Blaney.
Lake Michigan	4.46	......	.31	.02	2.20	......	......	.28	.30	......	......	......	.22	Trace.	7.82	J. H. Long.
Lincoln, filter gallery	7.30	......	6.76	......	4.73	......	.73	1.02	.71	......	......	2.31	......	......	16.07	Do.
Nashville Spring	......	......	65.8	......	......	......	......	......	......	24.0	......	10.0	53.0	......	265.5	W. F. Hillebrand.
Oregon, Ganymede Spring	9.20	......	......	.08+	8.56	......	......	.15	9.62	......	......	.10	......	......	20 0	E. W. Hall.
Perry, iron spring	......	15.89	73.94	......	......	17.0	......	......	1.31	......	......	......	.44	......	156.0	Henry Egbren.
Rockford, drift well	......	16.03	......	.39	......	11.43	......	.15	1.04	......	4.66	.11	.21	.08	29.94	E. G. Smith.
Spring Valley, spring No. 1	8.96	......	3.84	......	3.40	......	......	......	.24	......	......	34.80	35.16	......	129.24	J. V. Z. Blaney.
Versailles, magnesium spring.	14.60	......	Trace.	.06	8.95	......	......	......	1.40	+K 1.32	......	Trace.	......	......	26.33	G. A. Marnier.
Waukesha, Bethesda Spring	17.02	......	......	.04	......	12.39	......	.46	.74	......	1.26	1.16	.54	.12	35.71	C. F. Chandler.
Waukesha, Hygeia Spring	......	......	......	......	19.22	4.63	......	.69	.70	......	......	1.89	......	......	37.53	A. W. Palmer.
Waukesha, Silurian Spring	9.93	......	......	.13	......	6.83	......	......	.70	......	.03	.19	.29	.59	18.69	W. S. Haines.
Woodstock, drift well	16.59	......	......	.39	......	5.19	......	.30	1.04	......	5.29	5.06	4.44	.08	29.94	Do.

In the following table are arranged the best analyses of artesian waters that are available. The water in the majority of the wells is not from a single vein or water horizon, there being few wells in which casing is carried far into the rock. It is probable, however, that the water in the following wells is mainly from the St. Peter: Dekalb waterworks, Monmouth waterworks, Rockford 400-foot well, and Rock Island brewery. The water in the following is probably mainly from Potsdam: Clinton (Iowa) waterworks, Galena waterworks, Rockford waterworks, St. Louis (Mo.) Insane Hospital, Sterling waterworks, and Turner Junction railroad well.

In addition to the substances classified in the table, a few wells show measurable amounts of other substances. Thus, organic matter is reported as follows: Dekalb, 0.70 grain; Elgin Hospital, 0.99 grain; Moline Paper Mill, a trace. Magnesium chloride is reported as follows: Montezuma, Ind., 9.97 grains; St. Louis, Mo., 46.08 grains; Winnetka, Ill., 1.95 grains. Magnesium sulphate is reported as follows: Auditorium Hotel, Chicago, 11.90 grains; Hannibal, Mo., 72.21 grains; Milan, 0.75 grain. Potassium chloride is reported as follows: Barry, 8.57 grains; Montezuma, Ind., 2.68 grains; St. Louis, Mo., 0.86 grain. The Dekalb and Dixon wells show a trace. The Montezuma (Ind.) analysis reports several substances not mentioned in the other analyses, viz: strontium sulphate, lithium chloride, borax, and sodium bromide, each with "more than a trace;" sodium iodide, a trace; calcium phosphate, a trace; hydrogen sulphide, 3.728 grains. In the Oakpark and Turner wells potassium and sodium sulphates are not separated, and in the Oakpark well potassium and sodium chloride are not separated. In the Lagrange (Mo.) well 8.17 grains of potassium carbonate were found.

An analysis of the water from the Macomb artesian well has been made at the Survey office, by Mr. George Steiger, since the table was prepared. It is thought to represent fairly well the quality of water to be obtained from the St. Peter sandstone in western Illinois. The superintendent of waterworks, Mr. W. E. Thompson, states that an attempt was made to exclude water from the water-bearing beds above the St. Peter, there being a continuous iron casing with tight screw joints from the top of the well down to the St. Peter sandstone, packed at the bottom with rubber, which was expanded by screw pressure to completely fill up the space between the outside of the casing and the wall of the well. A similar packing was also put in at 145 feet, the beginning of the rock formation. It is scarcely probable, therefore, that water to any great amount enters the well from other horizons than the St. Peter sandstone. A comparison of the analysis of this water with the analysis of the unseparated waters from a neighboring well at Barry, Ill., reveals a great difference in the amount of sodium chloride, and raises the question whether the Barry well and all other wells in this part of the State may not be greatly improved by casing out the water above the St. Peter sandstone.

Analysis of St. Peter water, Macomb, Ill.

[Grams per 1,000 cubic centimeters.]

	Grams.
SiO_2	.0105
TiO_2	None.
SO_3	.8326
CO_2	.2899
Cl	.5418
P_2O_5	None.
O (basic)	.2732
Al	.0007
Fe	.0013
Ca	.1581
Mg	.0672
K	.0237
Na	.8086
Total	3.0076

Hypothetical combinations.

	Grams per 1,000 c. c.	Grains per U. S. gallon.
KCl	.0454	2.652
NaCl	.8570	50.063
Na_2SO_4	1.4555	85.025
$MgSO_4$	.0192	1.121
$MgCO_3$	.2218	12.956
$CaCO_3$	.3950	23.074
Al_2O_3	.0013	0.075
Fe_2O_3	.0019	0.111
TiO_2	None.	None.
SiO_2	.0105	0.613
P_2O_5	None.	None.
Total	3.0076	175.690

Analyses of artesian well waters.

[Grains per United States gallon.]

Locality.	Alumina.	Calcium carbonate.	Calcium bicarbonate.	Calcium sulphate.	Ferrous carbonate and bicarbonate.	Magnesium carbonate.	Magnesium bicarbonate.	Potassium sulphate.	Silica.	Sodium carbonate.	Sodium bicarbonate.	Sodium chloride.	Sodium sulphate.	Total.	Analyst.
Barry, waterworks				58.64	Trace.		16.89		84.0			217.7	62.6	367.0	(?)
Chicago, Auditorium	0.07		21.33	16.31	.13			1.58	.84			2.33	36.75	91.24	E. G. Smith.
Chicago, Leland Hotel		5.69			.304	0.24		.12	1.33	6.32		2.51		16.99	C. G. Wheeler.
Chicago, Munger's Laundry	.03		5.63		.04		7.45	Trace.	.49		7.03	1.82	.47	23.23	E. G Smith.
Clinton, Iowa, waterworks	Trace.		11.22		Trace.		7.42		6.1		6.28	6.6	6.6	38.8	Do.
Davenport, Iowa, glucose factory.	.36		5.13	5.54			4.77		.2			28.1	16.1	60.2	E. Guteman.
Dekalb, waterworks	.69		8.39				6.47					Trace.	1.13	17.5	G. M. Davidson.
Dixon, waterworks	.12		9.03	.06			9.94		.28			.4	.7	18.0	E. G. Smith.
East Moline	Trace.			2.52	.08		8.82	1.90	.57			27.2	19.1	70.4	Do.
Elgin, Insane Hospital	Trace.		8.39				4.41		.24	.73		1.4	1.77	18.1	W. Haines.
Evanston			10.82	22.46			7.82	19.42	.48			5.36	4.81	71.3	W. L. Brown.
Galena, waterworks	.66		3.70		Trace.		8.50	Trace.	.06			.10			W. Simpson.
Geneseo, waterworks	8.55	24.10	4.50		1.8 2.8	10.23						90 4	11.03	157.4	D. M. Stanner.
Hannibal, Mo., Oakwood well				125.89								712.28	77.26	987.64	R. Chanvent & Bros.
Jerseyville, waterworks	.06		6.84	16.9	.11		15.53	10.3	.78			85.9	5.05	141.5	E. G. Smith.
Lagrange, Mo., Wyaconda well.	.09		51.6				31.28		2.86		.20	320.6	9.22	424.05	(?)
Macomb, waterworks	.075	23.07				12.95			.61			50.06	85.02	175.69	George Steiger
Milan, town well	Trace.	6.26				1.50		7.43	.03	[1] 42.19		[1] 10.21		68.4	(?)
Moline, paper mill		8.76			.22	5.84			.35			27.85	28.84	71.9	W. Haines.
Monmouth, waterworks	.10		15.8	4.7	.23		14.07	4.86	1.04			9.61	23.4	73.9	E. G. Smith.

[1] Given as potassium in analysis, but probably sodium, and thus reported by J. A. Udden.

Analyses of artesian well waters—Continued.

Locality.	Alumina.	Calcium carbonate.	Calcium bicarbonate.	Calcium sulphate.	Ferrous carbonate and bicarbonate.	Magnesium carbonate.	Magnesium bicarbonate.	Potassium sulphate.	Silica.	Sodium carbonate.	Sodium bicarbonate.	Sodium chloride.	Sodium sulphate.	Total.	Analyst.
Montezuma, Ind	.07	....	11.18	10.66	....	....	17.88	....	.82	....	....	357.7	....	426.3	W. A. Noyes.
Oakpark, waterworks	....	8.16	....	Trace.	Trace.	2.33	....	....	.40	....	8.7	30.54	6.79	56.9	G. M. Davidson.
Peru, waterworks	.04	....	12.65	....	....	....	7.16	....	.79	....	7.02	16.0	7.25	50.9	E. G. Smith.
Princeton, waterworks	....	....	....	....	....	....	....	....	....	....	....	3.7	....	28.5	E. H. Bartley.
Rockford	.13	....	13.17	....	.07	....	12.79	.50	.58	....	.81	.27	.35	28.7	E. G. Smith. (?)
Rockford, waterworks	.06	....	13.83	.19	.15	....	12.28	.23	.54	....	....	.11	.34	27.8	Do.
Rock Island, brewery	....	10.0	....	....	....	6.3	....	....	....	4.0	....	32.00	15.00	67.3	Wall and Hennsock.
St. Louis, Mo., Insane Hospital.	....	....	47.49	50.18	.05	....	....	3.05	.93	....	....	401.5	....	550.2	P. S. Schwitzer.
Sterling	.05	....	14.85	....	.06	....	13.35	.46	.61	....	....	.69	.54	30.60	E. G. Smith.
Turner Railroad Co.	Trace.	6.67	....	.11	.12	4.08	....	....	.56	....	....	1.48	4.49	18.20	(?)
Winnetka, Lloyd's well	....	....	12.79	20.46	.87	....	4.85	3.86	....	....	1.69	2.48	2.65	51.60	C. E. Clacius.

CHAPTER X.

AN ACCOUNT OF THE PALEOZOIC ROCKS EXPLORED BY DEEP BORINGS AT ROCK ISLAND, ILL., AND VICINITY.

By J. A. Udden.

GENERAL STATEMENT.

Within a distance of 6 miles from the cities of Moline, Rock Island, and Davenport, 21 deep wells have been made, up to the present time (January, 1896), for the purpose of obtaining artesian water. The wells are scattered over an area extending 11 miles east and west and about 6 miles north and south. With the exception of the well in the

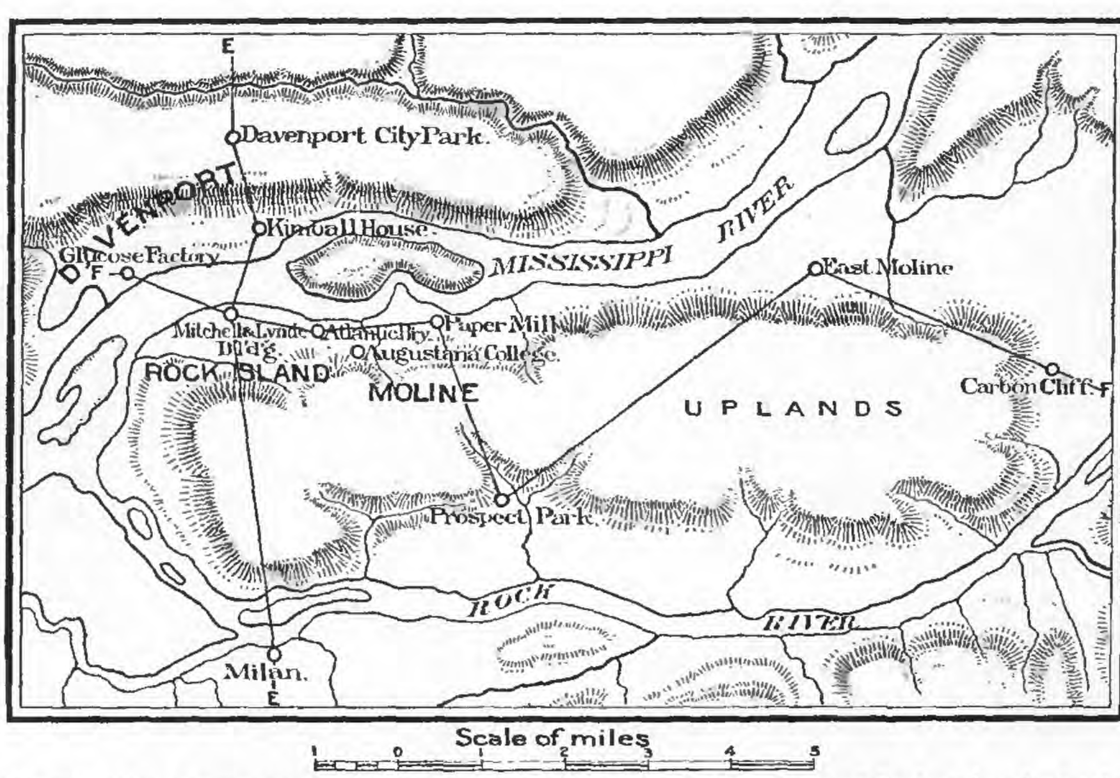

FIG. 71.—Map showing location of deep wells in Davenport, Moline, Rock Island, and suburbs, by J. A. Udden.

city park in Davenport, all are located on the bottom lands of the Mississippi and the Rock rivers, some of them just in the lower slope of the river bluffs. The well in the Davenport Park is the only one which has not furnished a flow of water.

Reports on the nature of the strata explored by these borings have been published in a few instances, but a comparative study of the obtainable data from this locality has not been made. At any rate, the results of such a study have not been placed on record.

The author has examined specimens of drillings from six wells, and

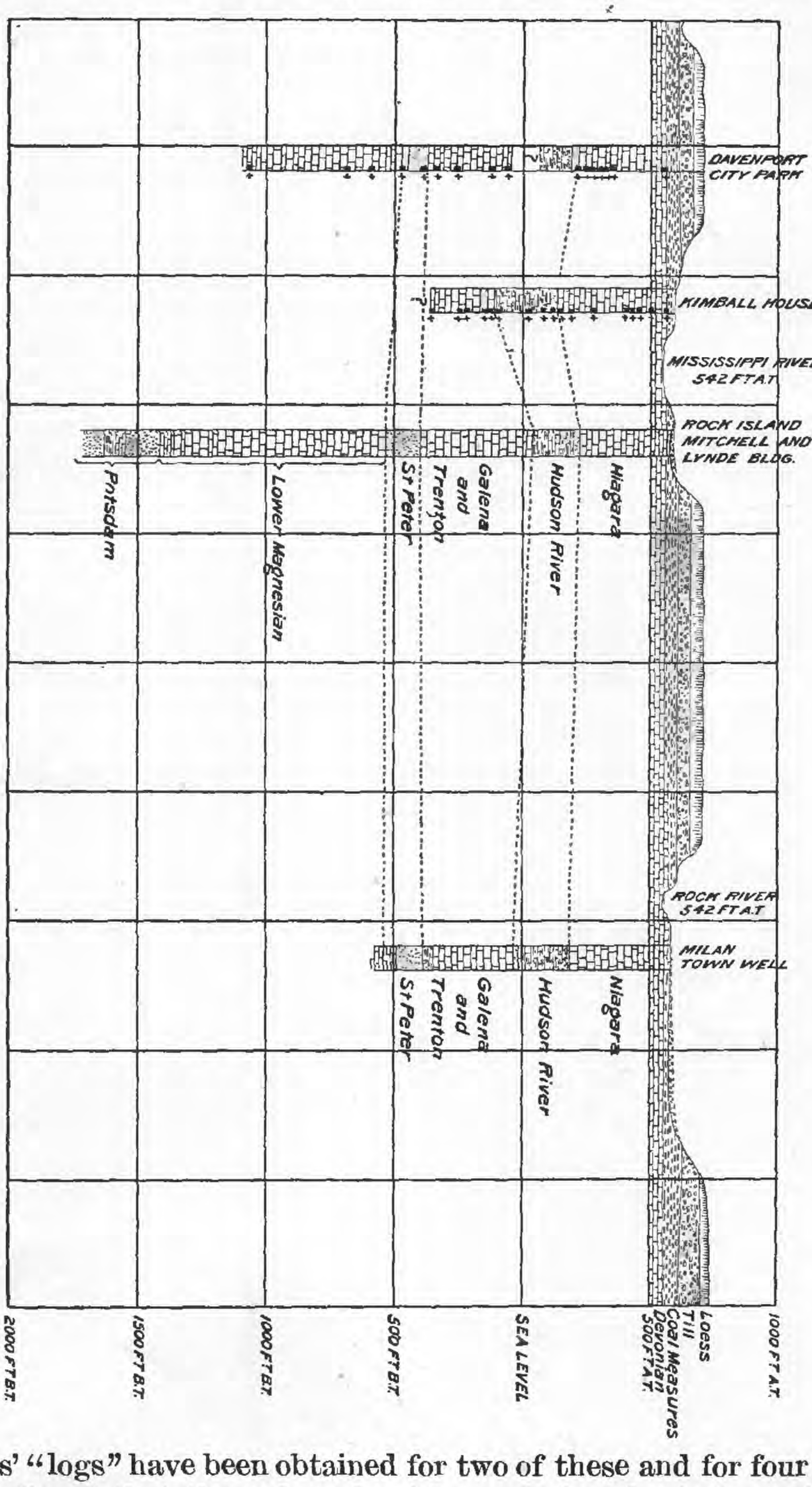

FIG. 72.—Geological section from Davenport, Iowa, to Milan, Ill.

drillers' "logs" have been obtained for two of these and for four others. It is believed that these data furnish a sufficient basis for estimating the thickness of the formations penetrated. They also throw considerable light on the lithological character of the rocks at different depths and on the geological structure of the area covered. (See figs. 72 and 73.)

The data which have been obtained may be found in condensed form at the close of this paper.

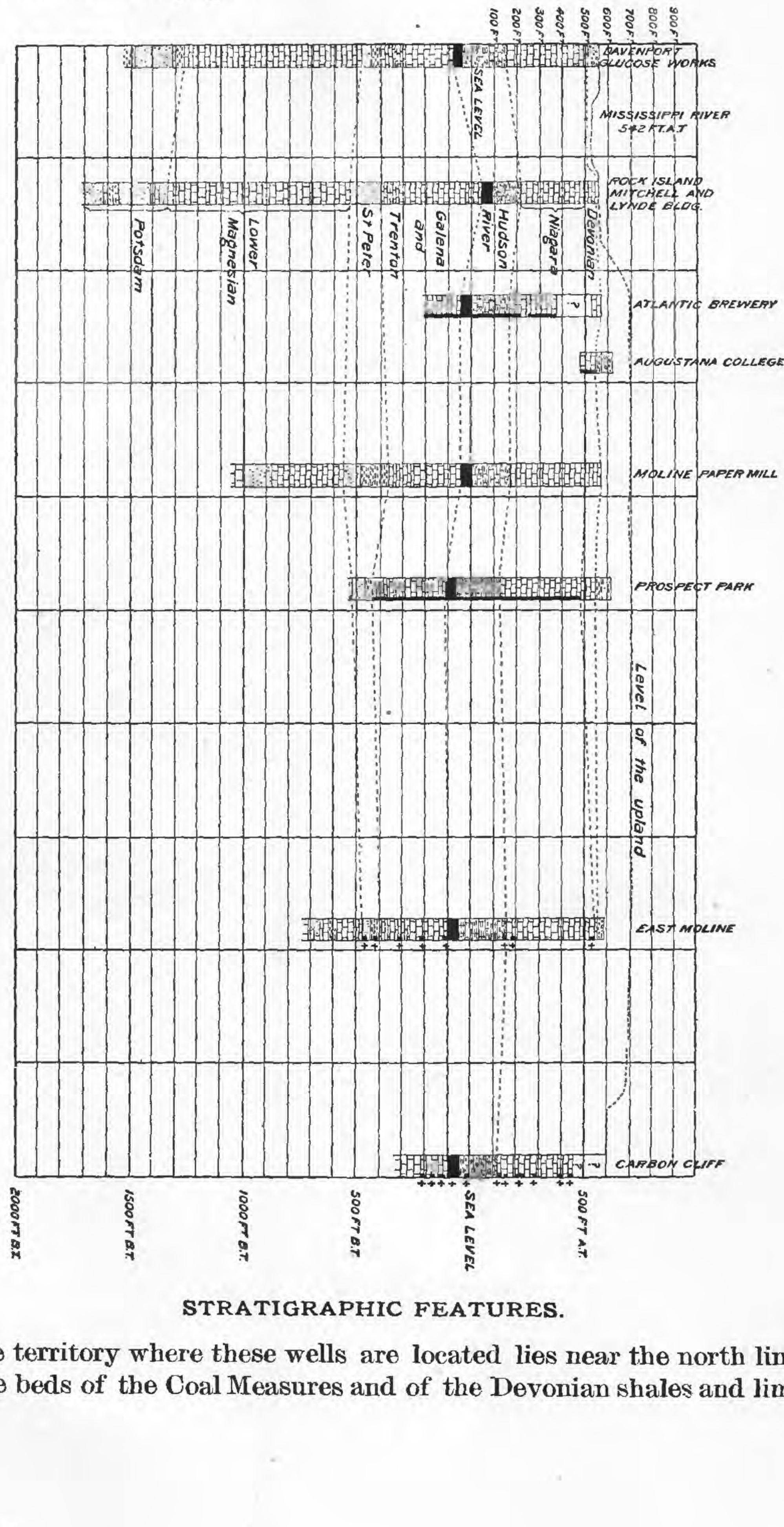

FIG. 73.—Geological section from Davenport, Iowa, to Carbon Cliff, Ill.

STRATIGRAPHIC FEATURES.

The territory where these wells are located lies near the north limit of the beds of the Coal Measures and of the Devonian shales and limestone. The Coal Measures have mostly been removed in the river valleys by recent erosion, and are now found only on either side of these valleys. The rocks immediately below consist of the feather-edge of the Devonian shales and limestone, which disappear a short distance to the north and east, and are succeeded in these directions and downward by the Silurian system. The drift and the Coal Measures are best studied in their natural exposures, but the Devonian rocks extend below the beds of the drainage valleys, and all the Silurian rocks are wholly concealed. In an account of the rocks explored by these wells the drift and the Coal Measures may therefore properly be omitted.

THE DEVONIAN LIMESTONE.

As known from exposures in this vicinity, the Devonian rocks consist of about 50 feet of shaly limestone, resting on a lower member of a pure white or dove-colored limestone, often brecciated, and variously estimated as being from 50 to 100 feet in thickness.

The thickness of the Devonian strata as exhibited in these wells varies from less than 10 feet to at least 100 feet, as may be seen from the following figures:

Table showing thickness of the Devonian rocks.

	Feet.
1. East Moline, from 551 to 541 feet above tide	10
2. Prospect Park, from 540 to 481 feet above tide	59
3. Augustana College, from 546 to 501 feet above tide	45
4. Mitchell & Lynde Building, from 558 to 498 feet above tide	60
5. Kimball House, from 567 to 467 feet above tide	100

These are all the wells in which the Devonian rocks have been separated from the Niagara limestone, which comes in below. In four of them the Devonian rock consists of the lower calcareous, massive, and brecciated ledges. At Augustana College, at the Mitchell & Lynde Building, and at Prospect Park there is nothing left of the upper argillaceous beds, which lie above the limestone, but in the Kimball House well, and possibly also in the Davenport City Park well, these beds were present.

The thickness of the lower limestone appears to be about 60 feet. It is underlain by dolomite. In the East Moline well this dolomite contained, near its upper limit, a joint of a crinoid stem, such as may be seen in the upper part of the Niagara limestone, where it comes up to the surface only a mile away.

In the drillings from the Kimball House well, now in the collections of the Davenport Academy of Science, fragments in every respect like the Devonian limestone are seen mixed with fragments of dolomitic Niagara limestone, and taken from a depth of 169 feet. The size of the fragments and their association with green clay make it probable that the Devonian rock, if really encountered at this level, was not in situ. It is possible that the fragments have dropped down from above in the hole, but there is some reason to think that blocks belonging to the upper rock may have come down in caverns. At any rate, Niagara limestone was taken out at a depth of 140 feet, and clay was found both above and below this depth in caverns.

Caverns may be seen in almost every quarry in the vicinity, and have been observed and described by several geologists who have examined the rocks of this region. Several if not all of the wells have given evidence of their existence. They appear to be particularly frequent near the contact of the Devonian and the Silurian systems. A shallow well on the river front in Davenport entered a cave at this level. In the Paper Mill well, at Moline, there was an empty cave 28 feet deep entered at 53 feet below the surface. In the well at Augustana College green cavern shale was noticed at a depth of 124 feet. The well at Carbon Cliff had to be curbed over 150 feet down to prevent the walls from caving. At this place the Devonian limestone comes up near by to within 10 feet of the surface. In the Milan well shale is reported as being found in the upper 300 feet of limestone. The top of this well starts in the lower solid ledges of the Devonian limestone, which is succeeded downward by the Niagara limestone.

The best evidence of caverns was seen in the drillings from the well at the Atlantic Brewery. This is only a few rods distant from the quarry where Professor Hall saw caverns in the limestone filled with clay in 1857,[1] and where such caverns may yet be seen, some filled with sandstone, some with clay, and one with a breccia containing large fragments of yellow chert. The uppermost sample from this well comes from a depth of 210 feet and consists of dolomitic Niagara limestone. The next sample was taken 10 feet deeper. Besides some pieces of a porous magnesian limestone and a fragment of a crinoid stem, evidently belonging to the same rock as the sample above, there are several lumps of shale like that in the caverns in the quarry, a piece of yellow chert, and several pieces of sandstone, also like that seen in the caves. Ten feet farther down there is a piece of limestone with a leached surface and a pebble of yellow chert. One-half of the sample is sandstone. Similar material, with green cavern clay, continues down to 270 feet, where the dolomite begins again. The almost invariable association of green clay with large leached and porous pieces of limestone in the borings is readily accounted for as being due to the existence of caverns partly or wholly filled with the clay. As long as the drill works in hard stone everything is pounded into fine fragments, and the harder the rock the finer the drillings will be, but when a cavern is entered the materials yield more readily and the borings accumulate in greater quantity before they are ground fine, and larger fragments are apt to come up in the bucket. Some of these are detached from the very walls of the caverns and show the roughness of surface and change in color due to erosion and leaching.

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[1] Geology of Iowa, James Hall, Vol. I, p. 130.

THE NIAGARA LIMESTONE.

In the nearest exposures of the Niagara limestone it immediately succeeds the Devonian limestone downward. It is dolomitic, and the estimates of its thickness for the nearest territory where it comes into view range from 175 to 300 feet. In its upper part it often exhibits an oblique, irregular bedding, is porous, has a dull yellowish-gray color where weathered, and frequently contains casts of fossils, among which stems of crinoids, gasteropods, and brachiopods are most common. This is a source for many windmill wells in the district north and east from Rock Island.

The lower two thirds of the formation is composed of horizontal beds of a compact bluish-gray rock, in which fossils are not numerous. In the lowest 30 or 40 feet nodular layers of white chert occur.

As explored in the wells, this limestone varies in thickness from 276 to 392 feet, averaging 340 feet.

Table showing thickness of the Niagara limestone.

	Feet.
1. Kimball House, from 467 to 132 feet above tide	335
2. Mitchell & Lynde Building, from 498 to 222 feet above tide	276
3. Prospect Park, from 481 to 125 feet above tide	356
4. East Moline, from 541 to 149 feet above tide	392

While the upper irregularly bedded part of this formation generally has a buff color in natural exposures, the samples of drillings from this horizon in the wells are white or even bluish-white, except where there is evidence of the existence of caverns, near which a faint rusty tint appears. In the Prospect Park well this tint prevails, although there are no certain indications of caverns. The porous character of the rock is well exhibited by the drillings from all the places. A thin bed of very hard rock is, however, penetrated in the Kimball House and Prospect Park borings about 250 feet above the base. Traces of fossil mollusks were seen in two cases, and casts of crinoid stems were found in four wells.

In the lowest 200 feet the rock is compact, but not very hard. Dark blotches are seen on the larger fragments. Except in the City Park well at Davenport, no fossils have come up from this lower depth. Pieces of white chert are found in all of the wells, with one exception, in the drillings from the lower 40 feet, and in the Atlantic Brewery well this chert constitutes the greater part of the sample.

THE HUDSON RIVER SHALE.

The thickness of the Hudson River shale (also called Cincinnati shale and Maquoketa shale) has been estimated for different places in Iowa, Illinois, and Wisconsin as ranging from 40 to 240 feet. It is by all geologists described as very variable in composition in the States named, changing from limestone through shale to sandstone. It is sometimes bituminous, and often contains iron pyrites, gypsum, and other substances as accidental minerals. Sometimes it is destitute of fossils, and sometimes it contains them in profusion.

As it has been explored in the wells, the Hudson River shale ranges in thickness from 182 to 265 feet, averaging 223 feet in nine of the wells. It is easily distinguished from the beds above it and below it, and the figures given relative to the dimensions of this shale may be considered reliable.

Thickness of the Hudson River shales.

	Feet.
1. Glucose factory, from 152 feet above tide to 73 below sea level	225
2. Kimball House, from 132 feet above tide to 108 below sea level	240
3. Mitchell & Lynde Building, from 222 to 40 feet above tide	182
4. Atlantic Brewery, from 157 feet above tide to 48 below sea level	205
5. Milan, from 176 feet above tide to 39 below sea level	215
6. Paper mill, from 169 feet above tide to 51 below sea level	220
7. Prospect Park, from 125 feet above tide to 110 below sea level	235
8. East Moline, from 149 feet above tide to 116 below sea level	265
9. Carbon Cliff, from 112 feet above tide to 108 below sea level	220

The lithological characters of the formation seem to be quite constant for the territory explored. Certain features persist for certain horizons in different wells. The upper 120 or 150 feet consist of a light-green or grayish-green shale, which is not at all or but slightly calcareous above, but which becomes a little more calcareous farther down. In the highest 20 feet fine arenaceous material enters as an ingredient in the rock, and fragments of bryozoans and brachiopods occasionally appear in the drillings. For the next 60 feet no fossils have been noticed. A little below the middle of the formation the shale becomes more calcareous and the color turns to gray. At this horizon crinoid stems have been found in nearly every instance where drillings have been taken, and they are associated with bryozoa, which appear in profusion in a sample from the Kimball House well. From this lower fossiliferous bed down to about 20 or 30 feet from the base of the shale pyrites is present more often than either above or below. The lowest part of the shale, from 20 to 50 feet, consists of a dark, occasionally almost black, bituminous shale. Several analyses show that it contains from 5 to 10 per cent of combustible matter. Seen under the microscope, this dark clay exhibits some peculiar brownish-yellow flakes, with an irregular outline and with an uneven surface. These particles are possibly of an organic nature. There may also be seen irregular agglomerations of small spherical grains resembling sedimentary flocculi. These occur throughout the entire shale, but they appear most frequently in the dark shale. Here they are composed of a greater number of particles than in the upper part of the beds.

THE GALENA LIMESTONE.

In Illinois and Iowa the Galena limestone is generally described as a drab-colored, subcrystalline magnesian limestone, and it is estimated as ranging in thickness in these States and in Wisconsin from 209 to 275 feet.

By well drillers this limestone is generally not reported separately from the underlying Trenton limestone. In the Prospect Park well and in the well at the Mitchell & Lynde Building the two have been identified separately, the upper rock being magnesian and the lower a more pure limestone. In the Milan well a change in color of the rock was noticed at the depth where the dividing plane should come in, and this change may perhaps be taken as indicating the contact between the two limestones. In these three wells the Galena limestone ranges in thickness from 200 to 353 feet, averaging 262 feet.

Thickness of the Galena limestone.

	Feet.
1. Mitchell & Lynde Building, from 40 feet above tide to 313 feet below sea level	353
2. Milan well, from 39 to 274 feet below sea level	235
3. Prospect Park, from 100 to 310 feet below sea level	200

For a depth of about 50 feet from its upper surface this rock appears as a light-gray, granular, dolomitic limestone. Fragments of bryozoa were seen in the drillings from the upper layers in the East Moline well. Below the upper 50 feet, or even a little higher up, the color changes to a shade of light drab or yellow, and this is the prevailing color all the way down to the Trenton rock. With this change there sometimes comes an admixture of fine sand, of grains of pure quartz, and of yellow, red, rose-colored, dark, and greenish quartz. At a distance of about 100 feet below the Hudson River shale some small spherical concretions of a brown color were observed in three wells. They somewhat resembled oolitic spherules. In the Carbon Cliff well a fragment of zinc-blende came from about the same depth. Quite a number of the samples from this limestone contain fragments of chert.

In the lower 200 feet a flow of water is invariably obtained, apparently at different depths in different wells, as indicated in the following table:

Levels of the upper artesian water, below top of the Galena limestone.

	Feet.
1. Glucose factory	165
2. Kimball House	50
3. Mitchell & Lynde Building	300
4. Atlantic Brewery	170
5. Moline Paper Mill	100?
6. Milan	200

The great range of the figures and the variable nature of the Galena limestone suggest that this water is not confined to any limited and well-defined horizon. Most probably it may be tapped at any level where the rock is sufficiently porous. It always smells more strongly of sulphurous gas than the deeper St. Peter water.

THE TRENTON LIMESTONE.

Within a distance of 130 feet upward from the top of the St. Peter shales and sandstone the drillings taken from the wells at East Moline, the Kimball House, Prospect Park, and the City Park in Davenport consist of limestone which promptly effervesces in cold dilute acid, and these samples are believed to belong to the Trenton limestone. The thickness, so far as known, ranges from 90 to 130 feet, averaging 103 feet.

Thickness of the Trenton limestone.

	Feet.
1. Mitchell & Lynde Building, from 313 to 403 feet below sea level	90
2. Milan (brownish limestone), from 274 to 364 feet below sea level	90
3. Prospect Park, from 310 to 440 feet below sea level	130

Chert is present in several of the samples. Grains of sand of various colors are to be seen. In one instance there was a fragment of a fossil. The rocks of this horizon appear to have a pronounced fissility in the direction of the bedding planes. The drillings consist largely of flat flakes, which may be ten times as long and wide as they are thick. The aspect of these flakes is quite unique, and they may be looked upon as characteristic of the rock at this level. It appears reasonable to suppose that these drillings come from such thin-bedded and laminated layers as have been observed in the outcrops of the Trenton limestone in other localities.

In four of the wells the Galena and the Trenton limestones have not been estimated separately, but their united thickness is known, viz: East Moline, 300 feet; Moline Paper Mill, 320 feet; glucose factory, 334 feet; Argillo Works, 358 feet. If the average of these wells, which is at least 328 feet, be averaged with the figures from the wells where the two limestones have been separated, we have 344 feet as the combined thickness of the Galena and the Trenton limestones.

THE ST. PETER SANDSTONE AND ASSOCIATED VARIABLE BEDS.

The accounts of this rock, as it is seen in the nearest outcrops, describe it as a siliceous sandstone, ranging from 10 to 250 feet in thickness. In some places a layer of green shale has been observed separating it from the limestone above.

In the wells here discussed it is found associated with beds of finer sediments above and below, together almost equaling the sandstone itself. In all the borings except one[1] a green shale overlies the sandstone and separates it from the Trenton limestone. Specimens have been examined from three wells, and in all cases it is a green, unctuous shale or clay, only slightly if at all affected by acid. It contains now and then good-sized rounded grains of quartz, a white, tough chert, exhibiting an irregularly reticulated structure on broken surfaces; also considerable pyrites, and lumps of more compact and darker shale. In the Paper Mill well, where the greatest development of this upper shale is reported, it was sandy, and contained "streaks of sandstone."

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[1] Mitchell & Lynde Building. Even in this well the shale may have been found, though not reported, as the record given by Professor Southwell merely gives his own determinations without any description of the nature of the rock.

Thickness of the variable beds above the St. Peter sandstone.

	Feet.
1. City Park, from 370 to 380 feet below sea level	10
2. Glucose factory, from 407 to 437 feet below sea level	30
3. Paper mill, from 371 to 511 feet below sea level	140
4. Milan, from 364 to 394 feet below sea level	30
5. Prospect Park, from 440 to 480 feet below sea level	40
6. East Moline, from 416 to 446 feet below sea level	30
Average	41

The St. Peter sandstone retains its usual character. In all the samples seen it consists of well-rounded grains of mostly clear quartz. In the East Moline well there was a notable admixture of opaque white grains and of reddish and greenish grains. It contains a never-failing supply of water, rising to a level of 650 feet above the sea level.

Thickness of the St. Peter sandstone.

	Feet.
1. City Park, from 380 to 470 feet below sea level	90
2. Glucose factory, from 437 to 479 feet below sea level	42
3. Mitchell & Lynde Building, from 401 to 546 feet below sea level	145?
4. Paper mill, from 511 to 576 feet below sea level	65
5. Milan, from 394 to 484 feet below sea level	90
6. Prospect Park, from 480 to 530 feet below sea level	50
7. East Moline, from 446 to 496 feet below sea level	50
Average	76

A bed of clay occurs again below the sand, but this is more variable than the clay above. In the Prospect Park well it is a green shale, which, as far as explored, is quite similar to the shale above the sandstone. In the City Park well at Davenport some of it is white, some green, and some purple-red. There are also some pyrites and some white and porous chert. Several of the pieces are gritty. In the Paper Mill well a "red marl" was found directly under the sand. In the East Moline well a "red marl" 35 feet thick was separated from the sandstone above by 105 feet of limestone. In this case both the limestone and the "red marl" may perhaps rather be regarded as belonging to the limestone below. But a somewhat similar succession was noticed in the Milan well, and here the resemblance is rather with the sandstone above. In this well 65 feet of "sandy limestone," "sand and limestone with shale and crevices," and "hard and sharp sandstone" follow under the St. Peter sandstone, and then there is a "red marl" 10 feet thick.

Thickness of the variable beds under the St. Peter sandstone.

	Feet.
1. City Park, from 470 to 500 feet below sea level	30
2. Milan, from 484 to 559 feet below sea level	75
3. Prospect Park, from 530 feet to well bottom	20+
4. East Moline, from 496 to 636 (?) feet below sea level	140?
Average	66

THE LOWER MAGNESIAN LIMESTONE.

In its nearest exposures to the north this rock is not known to much exceed 200 feet in thickness. It is described as a light-colored magnesian limestone, with chert and occasional intercalations of sandy and shaly material, especially in its upper part. From some deep wells in Iowa it is reported as being several hundred feet in thickness.[1]

Five of the wells are known to have entered this limestone, and two (really four, counting the several wells at the glucose factory separately) extend through it. Drillings from it have been examined by the writer from only one well, the one in the city park in Davenport. These consist of finely ground white magnesian limestone, with some admixture of sand, chert, and green shale. The records from the other wells describe it as "sandy limestone," "sandy magnesian limestone," or merely as "limestone." In the East Moline well there was a stratum of sand 3 feet thick 60 feet below the top of the limestone, and in the Paper Mill well alternations with shale are indicated for the upper part of the limestone. The rock below the St. Peter sandstone is there described as "red marl and limestone," extending down to 892 feet below the sea level. At this depth there was 121 feet of sandstone (called "Potsdam sandstone"), below which limestone again was encountered as far down as the well extended.

Thickness of the Lower Magnesian limestone.

	Feet.
1. City Park, from 500 feet below sea level to well bottom	503+
2. Glucose factory (one well), from 479 feet below sea level to well bottom	459+
3. Glucose factory (three wells), from 479 to 1,267 feet below sea level	788
4. Mitchell & Lynde Building, from 546 to 1,357 feet below sea level	811
5. Paper mill, from 587 feet below sea level to well bottom	487+
6. Milan, from 559 feet below sea level to well bottom	32+
7. East Moline, from 636 feet below sea level to well bottom	125+
Average (for four wells)	800

THE POTSDAM ROCKS.

The glucose factory wells and the well at the Mitchell & Lynde Building are the only ones which extend below the Lower Magnesian limestone. The writer has not seen any samples from either place. The drillings from the Mitchell & Lynde well were examined by Prof. J. H. Southwell, and he has reported these lowest formations in a more descriptive way than he reported the formations above. The data from the glucose factory wells were furnished by the drillers. This circumstance may perhaps explain some differences between the two accounts. Professor Southwell reports 30 feet of "compact sandstone" lying under the Lower Magnesian limestone. In the other wells there was 40 feet of "shale." The material may have been a somewhat indurated,

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[1] See thickness of the Paleozoic strata of northeastern Iowa, by William H. Norton: Iowa Geological Survey, Vol. III, p. 184.

fine-grained, clastic rock, alike in both wells, and verging on the border between the descriptions given, or there may have been a slight change in the bed horizontally. Under this there was in both wells a calcareous rock, 35 feet of "limestone" in the well at Rock Island, and 20 feet of "sandy limestone" in the well at Davenport. Then follow 130 feet of "sandstone" in the former well and 160 feet of "sandy rock" in the latter. In the well at the Mitchell & Lynde Building this rests on 75 feet of "shaly limestone and shale," and in the glucose factory wells there is 51 feet or more of "shale." Below this, again, the former well penetrated 97 feet of "sandstone." The close resemblance of the strata reported from these wells with the Potsdam series in Wisconsin reported by Prof. T. C. Chamberlin may be presented in a table, viz:

Table showing close resemblance of the strata with the Potsdam series in Wisconsin.

	Mitchell & Lynde Building.	Glucose factory.	Wisconsin section.
	Feet.	*Feet.*	
Compact sandstone or shale.	30	40	30 feet Madison sandstone.
Limestone, arenaceous	35	20	35 feet Mendota shale and limestone.
Sandstone	130	160	150 feet sandstone.
Shaly limestone and shale...	75	50+	80 feet shale.
Sandstone	97+	....	300 feet sandstone.
Total penetrated	347	270	

Judging from the position and the succession of these beds, there seems to be good reason to believe that the sections are equivalent. Another circumstance of the same import is the fact that the sandstone is water-bearing, and that the head of its flow is slightly higher than that of the water from the St. Peter sandstone.

In the following table of "thickness of the formations and elevations of the contacts" the main results of the study are presented.

This table is followed by a generalized geological section for Rock Island and vicinity, based upon this study.

Table of thickness of the formations and elevations of the contacts.

	Elevation of the curb above sea level.	Top of the Devonian limestone.	Thickness of the Devonian limestone.	Contact between the Devonian and the Niagara limestones.	Thickness of the Niagara limestone.	Contact between the Niagara limestone and the Hudson River shale.	Thickness of the Hudson River shales.	Contact between the Hudson River shale and the Galena limestone.	Thickness of the Galena limestone.	Contact between the Galena and the Trenton limestones.	Thickness of the Trenton limestone.	Contact between the Trenton limestone and the St. Peter sandstone.	Thickness of the St. Peter sandstone and associated beds.	Contact between the St. Peter sandstone and Lower Magnesian limestone.	Thickness of Lower Magnesian limestone.	Probable contact between the Lower Magnesian limestone and the Potsdam (?) series.	Explored thickness of the Potsdam (?) series.	Average elevation of contacts in each well above (+) or below (—) the averages of each contact in the several wells.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Glucose factory	562					152	225	*73*			[1]334	*407*	72	*479*	788	[2]*1,267*	270+	+10
City Park, Davenport	704	574			[3]357	217						*370*	130	*500*				+45
Kimball House	580	567	100?	467?	350+?	132	240	*108*										—33
Mitchell & Lynde Building	558	556	58	498	276	222	182	40	353	*313*	90	*401*	145	*546*	811	[2]*1,357*	367	+26
Atlantic Brewery	577					157	205	*48*										+ 8
Augustana College	626	546	45	501														
Paper mill	564	557			[3]388	169	220	*51*			[1]320	*371*	216	*587*				+ 1
Milan	566	559			[3]390	176	215	39	235	*274*	90	*364*	195	*559*				+19
Prospect Park	611	540	59	481	356	125	235	*110*	200	*310*	130	*440*	120+					—29
East Moline	579	551	10	541	392	149	265	*116*			[1]300	*416*	220	*636*				—23
Carbon Cliff	592					112	220	*108*										—44
Average				498		161		*68*		*299*		*398*		*550*				

[1] Including the Galena limestone.

[2] Omitted in the averages.

[3] Including the Devonian limestone.

NOTE.—The elevations are all referred to sea level, except in the last column. The figures in italics indicate distance below sea level.

EXAMINATION OF WELL DRILLINGS.

DAVENPORT, IOWA; WELLS AT THE GLUCOSE FACTORY.

[Elevation of the curbs of the wells, 562 feet above tide.]

At the glucose factory in Davenport four wells have been drilled close together, no two wells being more than 250 feet apart. The logs

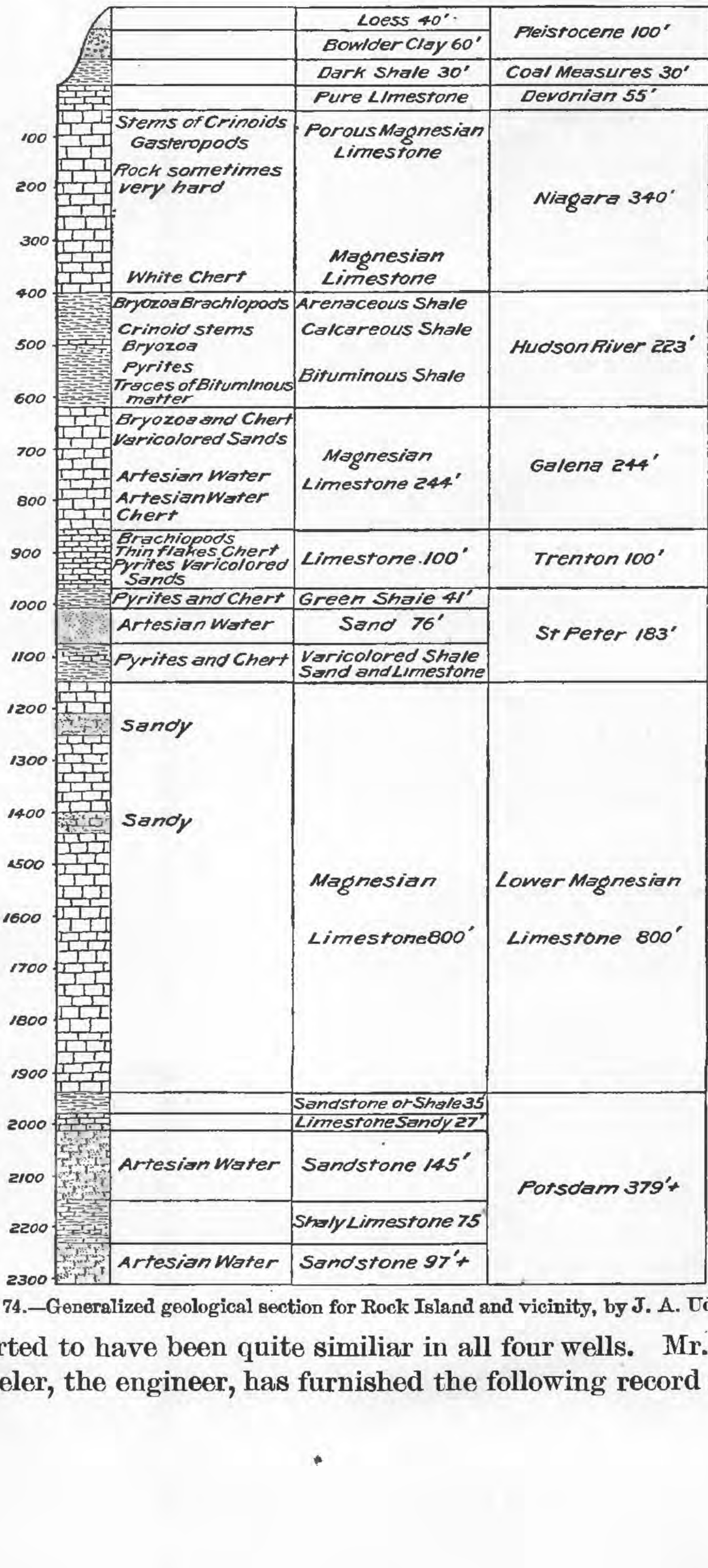

FIG. 74.—Generalized geological section for Rock Island and vicinity, by J. A. Udden.

are reported to have been quite similiar in all four wells. Mr. William Schoendeler, the engineer, has furnished the following record as representing the formations explored in one of the wells: Surface material, 52 feet; bluish limestone, 358 feet; shale, 225 feet; limestone, 334 feet; shale, 30 feet; sandstone, 42 feet; sandy limestone, 530 feet; no record, 258 feet (Mr. Schoendeler thinks the rock in this interval was sandy limestone like that immediately above); shale, 40 feet; sandy limestone, 20 feet; sandy rock, 160 feet; shale, 50 feet.

DAVENPORT, IOWA; WELL AT THE CITY PARK.

[Elevation of the curb, 704 feet above tide.]

Samples of drillings from this well were taken by Dr. A. S. Tiffany, who has published his determinations of the same in the American Geologist, Vol. III, p. 117. This set of drillings is the only one from this locality with samples from the Lower Magnesian limestone that the present writer has examined. It has been in the hands of several parties. The labels are extremely unsatisfactory, owing to the fact that they have been changed, erased, and rewritten in several instances. Uncertain depths are indicated thus (?). The following are the present writer's identifications:

1 (574 feet above tide): Compact calcareous limestone. Devonian.

2 (354[1] feet above tide): Yellowish magnesian limestone, some clay, and some eroded fragments, somewhat porous. Niagara.

3 (324 feet above tide): Large fragments of a porous, light, yellowish magnesian limestone, some fragments with apparently eroded surfaces. Niagara.

4 (304? feet above tide): Gray magnesian limestone, somewhat porous. Niagara.

5 (244? feet above tide): Almost pulverized magnesian limestone, cream-colored. Niagara.

6 (214? feet above tide): Fragments of a sandy gray shale, which have been washed out from the softer body of the shale or clay; a small brachiopod. Hudson River.

7 (54 feet above tide): Dark-gray magnesian limestone, with minute rounded dark and black grains. Galena.

8 (21 feet below sea level): Gray magnesian limestone. Galena.

9 (121? feet below sea level): Yellowish-gray magnesian limestone in fine fragments, and containing rounded minute nodules of pyrites. Galena.

10 (246 feet below sea level): Light-gray limestone, readily effervescing with acids, in fine fragments. Trenton.

11 (321 feet below sea level): Gray limestone, effervescing with acids, in thin, flaky fragments. Trenton.

12 (371 feet below sea level): Green clay, or shale, with some sand and pyrites. Shale associated with the St. Peter sandstone.

13 (376? feet below sea level): Somewhat coarse, well rounded, white sand, with a small admixture of grains of dark, green, and pinkish color. St. Peter sandstone.

14 (376+? feet below sea level): Like the above, slightly more yellowish. St. Peter sandstone.

15 (456 feet below sea level): White, purple, and green shale, in large lumps; some white chert and pyrites. Shale associated with the St. Peter sandstone.

16 (486 feet below sea level): Magnesian limestone in fine fragments, mixed with sand; a large number of fragments of a hard, green shale. The green fragments appear frequently to have been worn round. Lower magnesian limestone.

17 (546 feet below sea level): Like 16, but with a larger admixture of magnesian limestone. Lower magnesian limestone

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[1] Possibly 304 feet.

18 (596 feet below sea level): Same as 17, but finer and with less sand. Lower magnesian limestone.

19 (1,093 feet below sea level): Same as above. Lower magnesian limestone.

DAVENPORT, IOWA; WELL AT THE KIMBALL HOUSE.

[Elevation of the curb of the well, 580 feet.]

Two series of samples were taken from this well, one by Mr. A. S. Tiffany, and one by the curator of the Davenport Academy of Sciences. The samples in each series were taken at irregular intervals. The two sets complete each other. Workmen who were present when the well was made state that the depth of the well is 1,050 feet, the bottom being in sandstone. On a label on one of the samples taken by the curator of the Davenport Academy of Sciences is a note to the effect that a shale 240 feet in thickness began at a depth of 448 feet. Mr. Tiffany reports that the drift was 13 feet deep.

1 (567 feet above tide): Dove-colored calcareous limestone.

2 (500 feet above tide): White calcareous limestone, some few fragments of magnesian limestone.

3 (452 feet above tide): White magnesian limestone in rather large fragments, a few darker pieces, some shale and pyrites, casts of a gasteropod and of a crinoid stem.

4 (405 feet above tide): White magnesian limestone; some green shale.

5 (275 feet above tide): Grayish-white magnesian limestone.

6 (155 feet above tide): Same, in large fragments, with apparently eroded surfaces; also chips of white chert.

7 (132 feet above tide): Pieces of magnesian limestone, of dark shale and of gray arenaceous shale; also of concretions of pyrites, and a joint of a crinoid stem.

8 (15 feet above tide): Shaly limestone filled with Bryozoa; also some pyrites.

9 (*110* feet below sea level): Yellowish-gray magnesian limestone.

10 (150 feet below sea level): Yellowish-gray magnesian limestone, ground fine, a considerable admixture of sand of dark, black, yellow, and rose-colored grains.

11 and 12 (180?[1] and 220 feet below sea level): Yellowish-gray magnesian limestone, with some grains resembling white chert, fragments very fine.

13 (245 feet below sea level): Dull buff-gray magnesian limestone, ground up fine.

The samples taken by the curator at the Davenport Academy of Sciences are:

1 (567 feet above tide): Calcareous limestone.

2 (505 feet above tide): Green clay, with ground-up calcareous limestone.

3 and 4 (501 and 479? feet above tide): White calcareous limestone.

5 (470 feet above tide): Green clay.

6 (440 feet above tide): White magnesian limestone.

7 (411 feet above tide): Large lumps of white calcareous limestone (Devonian) and magnesian limestone (Silurian).

8 (411 feet above tide): White magnesian limestone, ground up fine, also some green clay. A note on the label says: "Hardest yet found."

9 (275 feet above tide): Green clay, with quartz sand.

10 (260 feet above tide): White magnesian limestone.

11 (220 feet above tide): Grayish magnesian limestone.

12 and 13 (180 and 155 feet above tide): White magnesian limestone.

14 to 16 (132, 80, and 40 feet above tide): Dark gray clay; calcareous at 40 feet.

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[1] Label obscure.

17 (90 feet below sea level): Almost black clay, distilling oil, and containing brown microscopic scales of irregular outline; also some rounded black grains.

18 (110 feet below sea level): Gray magnesian limestone, with a buff tinge.

19 and 20 (145 and 155 feet below sea level): Same, with some bluish fragments and some greenish grains.

21 (240 feet below sea level): Magnesian limestone of a faint buff color, with some darker fragments. A number of spherical concretions (?) were observed, ½ mm. in diameter and less, some single and some in groups of two and three. Their outer surface was reddish, and their form resembled that of oolitic spherules.

21a (240 feet below sea level): Magnesian limestone of a faint buff color.

22 (340 feet below sea level): Limestone, with some red and green grains of sand.

ROCK ISLAND, ILL.; WELL AT MITCHELL & LYNDE BUILDING.

[Elevation of the curb of the well, 558 feet above tide.]

Prof. J. H. Southwell was closely watching the progress of the drilling of this well in 1890 and 1893, and he has given to the proprietors of the well the following section of the rocks explored: Devonian limestone, 60 feet; Niagara limestone, 276 feet; Cincinnati shale, 180 feet; Galena limestone, 353 feet; Trenton limestone, 90 feet; St. Peter sandstone, 145 feet; Lower Magnesian limestone, 811 feet; Potsdam rocks: compact sandstone 30 feet, limestone 35 feet, sandstone 130 feet, shaly limestone and shale 75 feet, sandstone 97 feet.

ROCK ISLAND, ILL.; WELL AT ATLANTIC BREWERY.

[Elevation of the curb, 577 feet above tide.]

Specimens of borings were obtained from the proprietors three years after the well was made. The samples were mostly taken at intervals of 10 feet, but the set examined lacks the samples from the upper and from the lower part of the well. Prof. J. H. Southwell, who watched the work as it proceeded, has stated that the upper 150 feet of the hole was chiefly through sandstone. The Devonian limestone has been extensively quarried close by, and it exhibits several caverns, now filled with sand and clay of the Coal Measures. The total depth of the well is in the neighborhood of 1,100 feet.

1 (367 feet above tide): Grayish-white magnesian limestone, in large lumps.

2 (357 feet above tide): Same, porous; also a little shale, white sandstone, and some chert. A cast of a fragment of a crinoid stem was seen in the limestone.

3 (347 feet above tide): Eroded lumps of porous magnesian limestone; cast of a Murchisonia. A large part of the sample was sandstone. A good-sized pebble of yellow flint was observed. It resembled the yellow flint occurring in the basal conglomerate of the Coal Measures seen in the outcrops near by in old caverns.

4 (337 feet above tide): Chiefly sandstone; one dark pebble; some green clay.

5 (317 feet above tide): White sandstone and green clay.

6 (307 feet above tide): White magnesian limestone, sand, and flint pebbles.

7 (297 feet above tide): White magnesian limestone and some sandstone.

8 (287 feet above tide): White sandstone in large lumps.

9 (277 feet above tide): White magnesian limestone, sandstone, and a lump of pyrites.

10 to 12 (247, 217, and 197 feet above tide): White magnesian limestone; some sand.

13 (187 feet above tide): Mostly sand.

14 (177 feet above tide): Mostly white chert; large fragments of dolomite; a few fragments of sandstone.

15 (152 feet above tide): Greenish, slightly calcareous clay, with microscopic spherical grains of quartz. A joint of a crinoid stem was found.

16 (142 feet above tide): Greenish, slightly calcareous clay, with grains of quartz, as above.

17 (127 feet above tide): As above. Bryozoans and brachiopods in calcareous fragments.

18 (117 feet above tide): Greenish, slightly calcareous clay.

19 (97 feet above tide): Same, somewhat lighter in color.

20 (77 feet above tide): Gray shale, with fine sand and pyrites.

21 (67 feet above tide): Gray shale, with fragments of limestone, showing marks of fossils. One joint of a crinoid stem, apparently worn.

22 and 23 (57 and 47 feet above tide): Gray shale, with fragments of limestone and pyrites, traces of fossils. Bryozoan at 47 feet.

24 to 26 (37, 27, and 7 feet above tide): Gray calcareous clay or shale, with lumps of darker material.

27 to 29 (3, 13, and 23 feet below sea level): Gray calcareous clay or shale, with lumps of darker material. Pyrites at 13 feet.

30 (43 feet below sea level): Dark calcareous clay or shale, bituminous, with microscopic brown flakes of irregular shape, and with rounded agglomerations of minute dark particles.

31 and 32 (53 and 73 feet below sea level): Grayish-white magnesian limestone, with scattered fragments of chert.

33 to 45 (83, 93, 103, 113, 123, 133, 143, 153, 163, 173, 183, 193, and 213 feet below sea level): Yellowish-gray magnesian limestone. Green clay at 143 and 173 feet; chert at 153 feet.

ROCK ISLAND, ILL.; WELL AT AUGUSTANA COLLEGE.

A few rods to the southeast of the main building of Augustana College a well has been drilled to the depth of 150 feet. In this well the drift was nearly 50 feet in thickness. This rests on 30 feet of shales of the Coal Measures, a thin coal seam occurring at a depth of 70 feet. Under the Coal Measures there is 45 feet of compact calcareous limestone, identical with the rock in the Devonian outcrops near by. The lowest 25 feet of the well was in magnesian limestone, evidently belonging to the Niagara formation. The elevation of the curb of this well is about 626 feet above tide.

MILAN, ILL.; TOWN WELL.

[Elevation of the curb of the well, 566 feet above tide.]

The drillers of this well recorded the following data, published in the Milan News: Drift, 7 feet; white limestone with some shale, 383 feet; shale, 160 feet; shale with streaks of limestone, 55 feet; brown limestone, 95 feet; white limestone, 140 feet; brownish limestone, 90 feet; shale, 30 feet; sand, 90 feet; sandy limestone, 10 feet; sand and limestone with some shale and crevices, 35 feet; hard and sharp sandstone, 20 feet; red marl, 10 feet; white limestone, 32 feet.

MOLINE, ILL.; WELL IN PROSPECT PARK.

[Elevation of the curb, 611 feet above tide.]

Specimens of drillings have been examined from levels 10 feet apart for nearly the whole depth, as indicated below:

1 (540 feet above tide): Compact calcareous limestone, quartz, sand, and coal.

2 to 4 (510, 500, and 490 feet above tide): Compact calcareous limestone, some pyrites and sand.

5 (480 feet above tide): Compact calcareous limestone and some fragments of magnesian limestone, coal, and pyrites.

6 to 8 (470, 460, and 450 feet above tide): Whitish, straw-colored magnesian limestone, somewhat porous, fragments large. Crinoid stem at 450 feet.

9 and 10 (440 and 430 feet above tide): Grayish-white magnesian limestone, some fragments large and with eroded surfaces, cavern clay. Crinoid stem at 430 feet.

11 and 12 (420 and 410 feet above tide): White magnesian limestone. Cavern clay at 410 feet.

13 to 27 (400, 390, 380, 370, 360, 350, 340, 330, 320, 310, 300, 290, 280, 270, 260, and 250 feet above tide): White magnesian limestone with bluish tinge at 400; large fragments with eroded surfaces at 390; some blue clay at 370; pyrites at 360 feet.

28 and 29 (240 and 230 feet above tide): White magnesian limestone with a yellowish tinge, some large and porous fragments.

30 (220 feet above tide): Same, not porous, a cluster of small quartz crystals.

31 and 32 (210 and 200 feet above tide): Compact white magnesian limestone.

33 and 34 (190 and 180 feet above tide): Grayish-white magnesian limestone, in coarse and porous fragments, with crystals on some surfaces.

35 to 39 (170, 160, 150, 140, and 130 feet above tide): Grayish-white magnesian limestone, with fragments of white chert; green shale at 150; angular quartz grains at 130 feet.

40 and 41 (120 and 110 feet above tide): Buff-gray shale. Brachiopod fragments at 110 feet.

42 (100 feet above tide): Darker-gray shale.

43 to 47 (90, 80, 70, 60, and 50 feet above tide): Gray shale, with pyrites; a few fine sand grains. Color more greenish at 50 feet.

48 to 53 (40, 30, 20, and 10 feet above tide, at sea level, and 10 feet below sea level): Bluish-gray shale, microscopic spherical grains of sand. (?) Fragments of dark limestone at 30 and 10 feet.

54 (20 feet below sea level): Gray shale, octahedral and cubic crystals of pyrites; a fragment of a crinoid stem.

55 to 57 (30, 40, and 50 feet below sea level): Gray shale, microscopic spherules; latter in clusters at 50 feet.

58 to 61 (60, 70, 80, and 90 feet below sea level): Dark-gray shale, with brown microscopic flakes of irregular outline, possibly of organic origin. The shale is bituminous, distilling a brown oil and losing 9 per cent in weight on ignition.

62 (100 feet below sea level): Gray shale, microscopic spherules in clusters.

63 to 67 (110, 120, 130, 140, and 150 feet below sea level): Grayish dolomitic limestone, subgranular.

68 to 80 (160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, and 280 feet below sea level): Yellowish-gray dolomitic limestone. Chert at 210, 260, and 280; lumps of green clay at 270 feet.

81 to 90 (300, 310, 320, 330, 340, 350, 360, 370, 380, and 390 feet below sea level): Slightly straw-colored calcareous limestone, in quite coarse fragments; chert at 380; thin flat fragments at 390 feet.

91 to 94 (400, 410, 420, and 430 feet below sea level): Bluish-gray calcareous limestone.

95 to 98 (450, 460, 470, and 480 feet below sea level): Greenish clay, with rounded sand grains and white chert, occasionally with some pyrites; chert shows reticulated structure at 470 feet.

99 to 101 (490, 510, and 530 feet below sea level): Well rounded pure quartz sand.

102 and 103 (540 and 550 feet below sea level): Greenish clay, with pyrites and some harder rounded pieces.

MOLINE, ILL.; WELL AT THE PAPER MILL.

[Elevation of the curb of the well, 564 feet above tide.]

At the time this well was completed, Mr. W. H. Pratt published in the proceedings of the Davenport Academy of Sciences a record of the strata as given by the drillers. This record reads: Surface soil, 7 feet; Devonian limestone, 113 feet; Niagara limestone, 275 feet; Maquoketa shale, 220 feet; Galena and Trenton limestones, 320 feet; sandy shales and streaks of sandstone, 141 feet; St. Peter sandstone, 65 feet; red marl and limestone, 316 feet; Potsdam standstone (supposed), 121 feet; limestone, 50 feet. At a depth of 53 feet there was a cavern 28 feet deep, and a "strong sulphur water" was reported at a depth of 700 feet.

EAST MOLINE, ILL.

[Elevation of the curb, 579 feet above tide.]

Samples of drillings from this well were obtained from Mr. E. H. Pope, the president of the East Moline Company. These samples were taken at depths indicated below. A written record of the rocks explored was secured from the drillers just after the well was completed. It reads: Drift, 28 feet; limestone, from 28 to 430; shale, from 430 to 695; limestone, from 695 to 995; shale, from 995 to 1,025; sandstone, from 1,025 to 1,075; limestone, from 1,075 to 1,180; red marl, from 1,180 to 1,215; limestone, from 1,215 to 1,275; sand, from 1,275 to 1,278; limestone, from 1,278 to 1,340.

1 (549 feet above tide): Large fragments of compact calcareous limestone, with smaller fragments of the same and of magnesian limestone, all of white color. There was also some green clay and some reddish marly material. A crinoid stem.

2 (179 feet above tide): White magnesian limestone and some greenish clay.

3 (149 feet above tide): Grayish-white shale, with microscopic round grains in irregular agglomerations, one fragment of white chert, and a trace of a fossil. The chert is of the kind found in the base of the overlying limestone.

4 (56 feet below sea level); Dark shale, with bituminous material. It contained microscopic yellow flakes of irregular outline, some pieces of harder and darker material, and some pyrites of iron.

5 (116 feet below sea level): Rusty, gray, subgranular limestone, effervescing slowly with strong acid; Bryozoa.

6 (221 feet below sea level): White magnesian limestone in small fragments, with colorless, greenish, and pink-colored rounded sand grains, and with small, dark spherical concretions.

7 (321 feet below sea level): Dark and buff calcareous limestone, with brachiopods, pyrites, and crystalline calcite. The drillings split into thin flakes.

8 (421 feet below sea level): Green clay, with some darker lumps and pyrites.

9 (471 feet below sea level): Well-rounded quartz sand, with some opaque white, black, green, and rusty grains.

CARBON CLIFF, ILL.

[Elevation of the curb, 592 feet above tide.]

The specimens of drillings from this well were given to the writer by Mr. Milo Lee, proprietor of the Argillo works at Carbon Cliff. This gentleman stated that the well had to be cased 200 feet down from the top to keep the rock from caving in. The total depth of the well is in the neighborhood of 950 feet, and the driller stated that it stopped in limestone. The thirteenth sample was taken at a depth of 600 feet, and on the label of this sample was written the note: "The past 120 feet a dark shale."

1 (442 feet above tide): White magnesian limestone.

2 and 3 (432 and 422 feet above tide): Grayish-white magnesian limestone, with some darker fragments; pyrites at 422 feet.

4 to 6 (392, 292, and 252 feet above tide): White magnesian limestone in coarse fragments; dark fragments at 252 feet.

7 (232 feet above tide): White magnesian limestone, ground fine, and containing some sand.

8 (212 feet above tide): White magnesian limestone, with some gray shale.

9 to 12 (172, 152, 132, and 112 feet above tide): White magnesian limestone.

13 (8 feet below sea level): Green calcareous shale, with some darker fragments, some pyrites, and a joint of a crinoid stem.

14 (88 feet below sea level): Very dark, almost black, calcareous shale, with much pyrites and with thin microscopic yellow flakes of an irregular outline. In the closed tube the material distils a brown oil.

15 to 20 (128, 138, 158, 178, 218, and 223 feet below sea level:) Gray, somewhat granular, magnesian limestone; large fragments at 178 feet; some gray shale and a small fragment of zinc-blende at 223 feet.

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