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PART I.—METALS AND NONMETALS EXCEPT FUELS

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GEOLOGISTS IN CHARGE

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ILLUSTRATIONS.

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1909.

PART I. METALS AND NONMETALS EXCEPT FUELS.

C. W. Hayes and Waldemar Lindgren, *Geologists in charge.*

INTRODUCTION.

This volume is the eighth of a series that includes Bulletins 213, 225, 260, 285, 315, 340, and 380, "Contributions to economic geology" for 1902, 1903, 1904, 1905, 1906 (Pt. I), 1907 (Pt. I), and 1908 (Pt. I), respectively. These bulletins are prepared primarily to insure prompt publication of the economic results of investigations made by the United States Geological Survey.

As the subtitle indicates, the papers included are of two classes—(1) preliminary reports on economic investigations the results of which are to be published later in more detailed form; (2) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description.

These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded. They have been grouped according to the subjects treated and each group has been issued as an advance chapter as soon as it was ready.

By means of the bibliographies accompanying the several groups of papers these volumes also serve as a guide to the economic publications of the Survey and afford a better idea of the work which the organization is carrying on for the direct advancement of mining interests throughout the country than can readily be obtained from the more voluminous final reports.

The reports on work in Alaska have been printed in a separate series since 1905, the volumes so far issued being Bulletins 259, 284, 314, 345, and 379. Bulletin 442 (in press) covers the work done in Alaska in 1909.

Since 1906 the annual economic bulletin has been printed in two parts, the second part comprising papers on mineral fuels. These volumes for 1906, 1907, and 1908 are Bulletins 316, 341, and 381. Bulletin 431 will form Part II of the "Contributions" for 1909.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

Gold and Silver.

NOTES ON THE PLACER DEPOSITS OF GREATERVILLE, ARIZONA.

By J. M. Hill.

INTRODUCTION.

The information contained in this report was obtained by the author in the latter part of March, 1909, while engaged in a mining reconnaissance of the Patagonia and Nogales quadrangles, Arizona, under the direction of Waldemar Lindgren and F. C. Schrader. The writer is under obligations to Mr. P. J. Coyne, of Greaterville, for much valuable information and assistance in the field, and to Messrs. Joseph Anderson, Daniel Johnson, and Hughes for historical data.

Greaterville is 5,280 feet above sea level. It is east of the Santa Rita Mountains, about 3 miles from the summit of Melendreth Pass, whose elevation is 5,850 feet. The Nogales branch of the Southern Pacific Railroad crosses the head of the Cienega drainage basin about 8½ miles southeast of the town. The wagon road from Greaterville to Sonoita, the nearest station on that road, is 13 miles long, running 7 miles a little south of east to Cienega Creek, thence following south up that valley to the station, a distance of 6 miles. A trail of a little over 9 miles connects the two points. Mail is received three times a week, brought on horseback from Helvetia by way of Rosemont, a distance of 14 miles by trail.

In the early part of 1874 the old Yuba mine at the head of Hughes Gulch was operated in a small way. Some cerusite containing silver and gold values is reported to have been rich enough to send to San Francisco and still net $90 per ton. The St. Louis lead mine was located a short time later and produced some ore. In the latter part of 1874 A. Smith found placer gold.[a] The discovery started a rush to this camp, and in 1878 there were 76 American voters regis-

[a] Raymond, R. W., Mines and mining west of the Rocky Mountains, 1875, p. 390.

tered, besides a population of about 400 Mexicans. The Greaterville mining district, according to Mr. Coyne, was organized March 17, 1875, but was never recorded with the county officials.

In 1876 Raymond[a] reported that the gold was coarse and that nuggets worth from $35 to $50 were brought in to Tucson, the average running from $1 to $5. The gold yielded from $16 to $18 an ounce, and it was not difficult for a man to clean up 1 ounce a day. The largest nugget ever reported from the camp weighed 37 ounces.[b]

The gravels were first worked by rocker, as water was scarce. A number of Mexicans made their living by packing water in goatskin bags from Gardner Canyon, 4 miles to the south, charging 25 cents a burro load of 10 to 16 gallons. Mr. Coyne states that by 1881 all the richer stream gravels had been worked over, and men began to leave the camp. Until 1886 the Indians also were to be reckoned with.

At about this same time (1886) the placers were considered worked out, and the rich gravels unquestionably had been greatly depleted. The camp from 1886 to 1900 was practically "dead." In the latter year a slight revival of activity was brought about by the installation of hydraulic mining in Kentucky Gulch by the Stetson Company. After sluicing for a few months, however, work was stopped, and the camp has been idle since.

In 1909 a few Mexicans made a meager living from some gulch diggings, and an American was operating a dry washing machine on a patch of high gravels without much success. From 25 to 30 cents a day at that time was considered good pay.

PRODUCTION.

In 1883[c] the yearly production since the discovery of the camp was estimated to have been about $12,000, and for 1884[b] the total production was $18,000. Mr. J. P. Coyne estimates the total production of a few of the gulches as follows: Louisiana, $40,000; Graham, $100,000; and Sucker, $500,000. He further states that the total production of the camp to date probably amounts to $7,000,000. This estimate, though much higher than Burchard's, was corroborated by several old-time miners, who have been in a position to watch the production of the district. It is possible that the large figure may include the production of the deep mines as well as that of the placers.

The United States Geological Survey obtains information from bankers, storekeepers, and other purchasers of bullion, from which estimates of the production of the various placer camps are made.

[a] Raymond, R. W., Mines and mining west of the Rocky Mountains, 1876, p. 342.
[b] Burchard, H. C., Production of the precious metals in the United States, 1884, p. 46.
[c] Idem, 1883, p. 80.

According to this information the placer-gold production of the Greaterville district for the period from 1902 to 1908, inclusive, is estimated to be $29,500, or an average of $4,218 a year. The production in 1902 was very high and so raised the average, which is usually about $3,000.

DESCRIPTION.

The Greaterville placer area is a rather flat country cut by deep arroyos and marked near its center by two rounded knobs.

From the summit of the Santa Rita Mountains, which opposite this place are rather low, there is a gentle but deeply eroded slope to the Cienega Valley, 9 miles to the east. A number of major gulches trend a little south of east. These are usually intrenched from 20 to 70 feet below the general level. The banks rise steeply, in places precipitously, so that it is difficult to travel either north or south without wide detours. All the arroyos have numerous branches, and the whole area is one of slopes.

There is almost no surface water, except in the rainy season, when it is found in most of the larger gulches. Shallow wells in Empire, Ophir, Kentucky, and Big gulches are used for local needs, but do not give a large enough supply even for rocker washing.

About 4 miles south of Greaterville, in the first canyon south of Gardner Canyon, there is a permanent stream, fed from springs situated under the crest of Old Baldy Peak, 7½ miles southwest of town in an air line.

GEOLOGY.

The areal geology of the Greaterville district, as shown on the sketch map (fig. 1), may be roughly generalized in the statement that there are three north-south belts (1) of granite, (2) of siliceous shales and sandstones, and (3) of wash materials and gravels, covering the area; that the structure dips eastward at relatively low angles; and that this structure is modified by two intrusions, one of granite porphyry as a stock, the other of narrow rhyolite dikes.

A very coarsely granular to porphyritic granite covers the western quarter of the area shown in figure 1, sending out a long, narrow tongue to the southeast at its southern end, along the south side of Fish Canyon. This granite is probably pre-Cambrian. It is intensely weathered to a dull yellow-brown, and its surface is covered with a coarse sand composed of quartz and pink feldspar particles up to one-half inch in diameter. The constituents in order of their abundance are orthoclase, plagioclase (not determined), quartz, biotite, hornblende. No fresh specimens of this rock were found, so little could be learned from thin sections. The general structure of the granite is a series of joints in a north-northwest to south-southeast direction, which cuts a sheeting that dips at flat angles eastward. In this granite there are numerous minor faults; one system strikes approximately east-west and the other parallel to the jointing. Some of these fault fissures are filled with quartz; at other places there is little to show their location. A few small rhyolite dikes were noted, their location being shown on the sketch map (fig. 1).

The southern limit of this granite is a fault that brings the granite against Devonian (?) limestone, though here and there a small crop-

FIGURE 1.—Sketch map of the Greaterville, Ariz., placer camp, showing distribution of dikes, veins, formations, and placer gravels, and the location of deep mines and gulches. Topography enlarged from Patagonia sheet, United States Geological Survey. Contour interval, 500 feet.

ping of what is probably Cambrian quartzite is found between the two. This limestone forms a prominent ridge about a mile south of Fish Canyon (Big Gulch), running southeast for nearly 5 miles, only a small portion of which is shown at the southwest in figure 1. The beds, dark blue-gray, thin and occasionally cherty, dip steeply to the southwest and are not fossiliferous. Their age was suggested by fossils found in similar limestone about one-half mile south of the center of the area shown.

In the extreme southwest corner of the region covered by the sketch map is a small area of red sandstones and shales of Mesozoic, possibly Cretaceous age. These beds are thin and dip steeply to the southwest.

East of the granite belt is a zone about 2 miles in average width underlain by thin-bedded arkose, sandstone, dolomite, and mud stones or shales. At the north end they dip to the east-southeast at angles of 5° to 10°. At the south end, along the granite tongue, the dip is from 70° to 80° NE. In the central part of the area, about the intrusive mass of Granite Mountain, the general structure is very different, the beds everywhere dipping away from the intrusive dome at high angles. The colors in this belt range from almost black, for the dolomites, through dull greens and reds in the quartzites, sandstones, and shales. North of Granite Mountain, where the beds dip at low angles, there is a covering of soil, supporting grass, scrub oak, and a few pines. South of the mountain, where the bedding is almost vertical and there are many gulches, there is comparatively little soil and many exposures of the rock. Small dikes and sills of a dense white porcelain-like rhyolite cut the sedimentary rocks in many places, a few of which are shown on figure 1. The age of these beds is uncertain, but from their lithologic character and their relation to the granite, being deposited on its eroded surface, they have been referred to the Cambrian.

Eastward from the Cambrian belt and covering nearly half of the area of figure 1 is a broad soil-covered area of gravel and wash material of Quaternary age. The contact with the older rocks dips to the east at about 40° in almost all places. Where this contact is exposed in the gulches no conformity is shown, as the shales are thin bedded and dip at high angles to the east, while the younger deposit shows an imperfect bedding, dipping at very low angles in the same direction. It is composed of pebbles and cobbles of all the rocks exposed in the region, partly cemented by lime. It is rather white in appearance, as the constituent bowlders are coated with lime. Mr. Coyne states that a shaft was sunk through this deposit about a mile east of the contact for a depth of over 100 feet without encountering any other formation.

Covering the formations of the eastern half of the area there is a deposit of finer gravel and soil, probably of recent age. It overlaps on the ridges the tilted beds of the Cambrian (?) as well as the lime-cemented Quaternary, but has been carried away from the gulch sides to be deposited in their bottoms.

Besides the rather small rhyolite dikes and sheets there is one intrusive rock of prominence in the area. This forms "Granite

Mountain," a knob that rises to an elevation of 5,500 feet from the general level of 5,000 feet. This hill is about 1¼ miles west-southwest from Greaterville and is a rather conspicuous topographic feature of the region. The granite in hand specimens is white and appears to be made up of feldspar and quartz with a rather large amount of pyrite and a little chalcopyrite widely disseminated through it. It is in some places porphyritic, but more commonly appears granular In most facies a little biotite is present, but in some of the exposures the dark minerals are absent. The weathered surfaces are yellowish brown and contain casts of pyrite surrounded by brown halos. Under the microscope the texture is seen to be granular to slightly porphyritic. Alteration has gone rather far, chlorite and kaolin being common in all the slides. The minerals in order of their abundance are orthoclase, quartz, plagioclase (usually much altered), and biotite. A little magnetite is present as accessory and pyrite is disseminated throughout the rock.

This knob is entirely surrounded by thin-bedded silicified dolomites and hornfels. The contact is not visible at many points, but where seen in some tunnels on the north side of the hill it was sharp. There was, however, a zone of several feet in which the sedimentary rocks were impregnated with quartz, some calcite, pyrite, and chalcopyrite, the latter two minerals giving a dark-brown cropping stained with malachite and azurite.

DISTRIBUTION OF GOLD-BEARING DEPOSITS.

On the sketch map only the location of the placer channels is shown; no indication of their actual width could be made on such a small scale.

SITUATION OF DIGGINGS.

The principal diggings are in the bottoms of the gulches, though channels of older gravels are found crossing the ridges or on the sides of the present valleys. Just south of Greaterville and about 30 feet above the present valley there is a small area of high gravel, and northeast of the town a similar deposit is seen on the crest of the ridge. Westward up Hughes Gulch a few small remnants of the high gravels are seen 15 feet above the bottom on the north side of the gulch, below the mouth of Nigger Gulch. This old channel apparently followed a depression along the present drainage way to a point just west of Greaterville, then possibly swung north parallel to the road between Greaterville and Enzenberg and about 200 feet west of it, supplying the values of the west head of Chispa Gulch. The connection between the gravels of Chispa and Hughes gulches is not apparent, as the upper part of Ophir Gulch, west of Greaterville, is barren and no gravels seem to cross it. The intervening gravels, however, could well have been removed during the erosion of Ophir Gulch, which is one of the larger drainage lines. An east arm of Chispa Gulch, just south of Enzenberg, contains placer gold. This gold was evidently derived from a ledge on the divide between this branch and Los Pozos and Colorado gulches.

PRODUCTIVE GULCHES.

The productive gulches were Boston, Kentucky, Harshaw, Sucker, Graham, Louisiana, Hughes, Ophir below its junction with Hughes, the upper parts of Los Pozos and Colorado, Chispa on the road from Enzenberg camp to Greaterville, and Empire below its junction with Chispa.

Boston Gulch.—Boston Gulch heads in the col south and west of Granite Mountain and trends a little south of east. Gold was found in paying quantities in this valley from its head to a point about one-half mile south of its junction with Kentucky Gulch at the Kentucky camp. In the upper 2 miles of its course the gold was found in a channel 5 feet wide on bed rock, 2 to 4 feet below the surface. Below Harshaw Gulch the values were still confined in a 10-foot channel in the valley bottom, being 5 to 10 feet below the surface. Below the mouth of Kentucky Gulch the valley is wide, and for half a mile below this point the values were distributed on bed rock at a depth of 10 to 16 feet for a width of approximately 50 feet.

Harshaw Gulch.—Harshaw is a short tributary of Boston Gulch. It is very precipitous, heading near Kentucky Gulch. Bed rock is exposed all along and the pay channel was confined to the bottom of the narrow V, rarely over 4 feet wide. In this gulch some very rich gravels were found.

Kentucky Gulch.—Kentucky Gulch heads south-southeast of Granite Mountain and joins Boston Gulch at Kentucky Camp. Values were found on bed rock for its entire length in a 6 to 10 foot channel. At the upper end the auriferous gravels were directly on the surface, becoming deeper down the gulch until at its mouth the pay was 6 feet under the surface.

Sucker Gulch.—Sucker Gulch has three small heads southeast of Granite Mountain. The gravels in this gulch were productive to a point a little below its junction with Ophir Gulch. From its head to the mouth of Graham Gulch the pay channel was 6 to 9 feet wide and 3 to 12 feet below the surface. Between Graham and Louisiana gulches the pay channel averaged from 20 to 50 feet in width and the depth was from 12 feet at the former to 25 feet at the latter gulch. Below the mouth of Louisiana Gulch the values were found distributed through the gravels on bed rock for a breadth of 100 feet. The overburden at the lower end was excessive, so not a great deal of work was done.

About 10 feet above the present channel there are in a few places in the upper part of this gulch small "bars" of pay gravels. These were evidently accumulated by the stream at some time previous to its present period of erosion and are simply remnants of its old channel.

Graham Gulch.—Graham Gulch is a short branch of Sucker heading southwest of the St. Louis mine. The bottom is about 100 feet wide at its lower end, and the pay gravel covered the whole width on bed rock 12 feet below the surface. At its upper end the channel was 10 feet wide and was covered by about 6 inches of soil. Some gravels 15 feet above the present channel on the south side of the gulch were productive.

Louisiana Gulch.—Louisiana Gulch heads about one-fourth mile south of Greaterville, is a little over a mile long, and joins Sucker Gulch. At the head values were found almost at the surface, but near the mouth they were 10 to 12 feet below the surface. The channel in this gulch split and reunited, but was generally about 6 feet wide.

Hughes Gulch.—Hughes Gulch runs north of Granite Mountain, heading just south of the Yuba mine, 2 miles west of Greaterville. A narrow channel, rarely over 6 feet wide from its head to its mouth, was found productive at 2 to 6 feet below the surface.

Nigger and St. Louis gulches.—Nigger and St. Louis gulches are small tributaries of Hughes Gulch. The former is west and the latter east of Granite Mountain. Both of them contain small gold-bearing gravel channels.

Ophir Gulch.—Ophir Gulch heads northeast of the Yuba mine but contains no placer deposits above its junction with Hughes Gulch. Below Greaterville a channel 200 feet wide was found to contain values as far as the junction with Sucker Gulch. The bed rock is rather deep and little work has been done here.

Los Pozos and Colorado gulches.—The upper 3,000 feet of Los Pozos Gulch was found to contain placer values. This gulch heads about a mile northeast of Greaterville. Colorado Gulch, about one-half mile north of Los Pozos, is a short branch of Empire Gulch. For 2,000 feet near its head some gold was found at no great depth below the surface.

Chispa Gulch.—Chispa Gulch is a small branch of Empire Gulch heading southwest of Enzenberg. In the main gulch, about three-fourths of a mile south of Empire Gulch, the highest pay gravels were found. A 5 to 10 foot channel on bed rock, about 10 feet below the surface, was productive and was being worked by Mexicans in the latter part of March, 1909. In an east branch gold was obtained from gravels 3 feet under the surface for a quarter of a mile from Chispa. The western fork of Chispa Gulch is about 1 mile long. At the head pay dirt was directly on the surface. At the mouth a 50-foot channel on bed rock, with 10 feet of overburden, contained values.

Empire Gulch.—Placer gold in Empire Gulch was found only for a mile and a half below the mouth of Chispa Gulch. Near the mouth of the latter gulch the pay gravels were about 300 feet wide, but at the lower end the values were distributed over 1,000 feet. The overburden is 16 feet thick and the pay dirt 2 feet thick on a conglomerate bed rock.

CHARACTER OF GRAVELS AND BED ROCK.

The pay dirt is found on bed rock distributed rather evenly through a 2-foot bed of angular gravels in a fine red-brown, somewhat clayey matrix. Some of the gravels are yellow to gray-brown, but these as a rule were not so rich as the heavily iron-stained beds. The conditions were essentially the same in all the gulches, and the thickness of the pay varied little from place to place.

The constituents of this bed are rather fine, usually less than 1 inch in greatest dimension, though in many places cobbles of 4 to 8 inches are found. In a few places the materials of this bed are roughly stratified and somewhat cemented, usually by lime.

The constituent pebbles are very angular and show almost no water wear. Even the sand consists of angular broken fragments rather than rounded grains. The coarse material is red and yellow sandstone, shales of various colors, pebbles of arkose, a few fragments of dense white rhyolite, and a very minor amount of granite porphyry. In Kentucky and Empire gulches particles of quartz and feldspar showing crystal faces were noted, evidently derived from the granite area where these gulches head. These pebbles are held together by a red-brown clay, not very difficult to handle with water.

The depth of this bed varied in the different localities, being almost at the surface in the heads of the gulches and buried to depths of 10 to 20 feet in the lower eastern ends of the diggings.

The Cambrian (?) sedimentary rocks form a perfect bed rock in the upper parts of the gulches. The beds are standing on edge, and their differences in weathering, due to difference in hardness, have formed natural riffles, behind which the gold has been concentrated. In the lower parts of Kentucky, Sucker, Ophir, and Empire gulches the "cement rock" (the Mesozoic cemented gravels) forms the bed rock and its rough surface has acted as riffles. The bed rock in Colorado, Los Pozos, and Louisiana gulches is entirely "cement rock." This shows that the concentration of the gold has been at least later than early Quaternary.

CHARACTER OF THE GOLD.

Most of the gold from this camp brought from $16 to $19 per ounce, that from Louisiana Gulch being the finest. The gold that was washed in 1909 was in rather small flakes up to 0.1 inch in longest dimension. Some of it is rusty, but the largest part is bright. It is said, however, that in the early days of the camp the gold was very coarse and that pieces whose value was $1 to $5 were commonly found.

Under the microscope the flakes are seen to be very angular, with many projections which would have been worn off if the material had traveled far. One of the large particles contained a small crystal of quartz completely surrounded by gold. Another showed what appeared to be a little galena with the gold. Mr. Coyne states that in the large nuggets it was common to find this association of quartz and galena with gold.

Concentrates from panning consist of about equal parts of magnetite and light-colored minerals that are apparently quartz and a little feldspar. The light-colored grains are somewhat stained with iron. All this material is angular and a few crystal faces (?) of quartz were noted.

ORIGIN OF THE GOLD.

The most productive gulches, Boston, Kentucky, Sucker, Graham, Louisiana, and Hughes, all head about the intrusive mass of Granite Mountain. This intrusion, as already stated, is of granite porphyry containing pyrite and chalcopyrite in appreciable amounts. About its base, in the altered, crumpled sediments of the supposed Cambrian, are found numerous quartz veins carrying galena, pyrite, and chalcopyrite, which are reported to have produced surface ores rich in gold and silver. These veins have been opened at the Yuba, Quebec, and St. Louis mines, as well as in numerous other places. They show very similar characteristics in all exposures. A gangue of quartz, with barite in some places, is banded with argentiferous galena, pyrite, and chalcopyrite. These usually form a stockwork in hornfels, quartzites, sandstones, and shales. The ore is in places wide enough to be called a vein.

The surface ores are much iron-stained quartz with scattered patches of malachite, azurite, or yellow earthy cerusite. It is said that several nuggets of native gold associated with quartz and galena were found in the croppings, particularly in the St. Louis vein.

The weathering of these veins and the attendant transportation of the material by the present streams would adequately account for the concentration of the placer gold in the gulches. The gravels between the gulches, however, contain values which could be accounted for either by sheet wash or by the transportation of the weathered material before the present drainage lines were well established. Concentration by wash from the ridges into the present valleys would further enrich the gold-bearing channels. The complete concentration on bed rock, however, points to frequent movement along the present channels, shaking the gold to the bottom.

The origin of the gold in Los Pozos and Colorado gulches is not so evident, as no ledges have been found on the divide between them and Chispa Gulch. This area is covered by considerable accumulations of wash material, so that prospecting is difficult; and this fact may account for the lack of discoveries of veins in the vicinity. The gold in the west branch of Chispa Gulch may be accounted for either by supposing that the old Hughes drainage turned north at Greaterville to enter the larger drainage of Empire Gulch, or that there are some gold-bearing ledges, not yet discovered, on the divide between this west branch and Ophir Gulch. The validity of the latter supposition is affected by the fact that no values were found in Ophir Gulch above its junction with Hughes Gulch. It is possible, however, that the veins which supplied Chispa Gulch are so far north that none of the branches of Ophir Gulch touch them. The richness of the gravels of Chispa Gulch indicates a rather long period of concentration or very rich primary deposits, and as no veins have been found at its head the former supposition seems the more tenable.

The theory of the origin of the gold from the veins about Granite Mountain is further supported by the fact that in the upper part of Empire Gulch, to the north, and in Fish Canyon (Big Gulch), to the south, no gravels of value have been found. These gulches, the largest in the region, head in the Granite area. There are some few widely scattered prospects in the granite, but the veins apparently carried little gold, except in the Yuba mine.

Furthermore, the fact that the gravels of the placers are largely derived from sedimentary rocks instead of granite shows that the gold did not come from the region west of Granite Mountain.

METHODS OF WORKING THE DEPOSITS.

Water is extremely scarce in the Greaterville placer district, so the means of working the gravels are limited. Dry washing has not proved a great success, as considerable clay is found in the pay dirt. Rocking has been the chief method employed for the recovery of the values.

Small shafts, usually 2½ by 5 feet in cross section, are sunk through the overburden, where it exceeds 3 or 4 feet in depth, to the bed rock. The gravels next to bed rock and for 2 feet above it are gouged out and hoisted to the surface by crude hand windlasses. In some of the pits seen the gravels for a radius of 20 feet were excavated from one small shaft. No lagging was used and there was apparently a constant menace of caving.

When there was a sufficient accumulation of the bed-rock gravels to supply the rockers for a few days, water was purchased and the extraction of the gold commenced. Usually two men worked together, but often one man would break down, hoist, and rock his gravels alone.

Two larger undertakings in the way of placer operations failed, possibly because the concentration of the values on bed rock necessitated the handling of so much valueless overburden. One company installed a 1-ton steam shovel, screens, and conical concentrating tank in Empire Gulch just below Enzenberg. After excavating an area 50 by 100 feet to a depth of 20 feet operations were suspended, as the pay dirt was not rich enough to warrant the removal of the 16 feet or more of overburden. The machinery was left in the pit and is fast being buried by slumping from the sides.

In Kentucky Gulch, at its junction with Boston, the Stetson Company tried hydraulic operations. Water was taken from the first canyon south of Gardner Canyon and carried through an 8-mile pipe line giving a head of 125 feet. The company sluiced 1,000 feet of the creek bed for a width of 30 feet. The gravels in the overburden are rather coarse and the pay is reported to have been too low to warrant further work. The pipe line is still in good repair and the company put up very comfortable quarters at Kentucky camp. It is reported that the 3,000 acres of patented land belonging to this company has lately been acquired by G. B. McAvery, of San Jose, Cal.

FUTURE OF THE CAMP.

The richer gulch gravels of the Greaterville district have been worked over to a considerable extent, but it is possible that some pay channels have not yet been found. The ground that has been washed still contains some gold, as is shown by the production of the few Mexicans who are working in localities known to have been productive. The gravels on the sides of the gulch and covering the ridges also contain small quantities of gold. E. Ezekiel, a mining engineer, of Tucson, who has examined the gravel deposits for a company, states that in the 8 square miles covered by placer gravels there are still probably nearer $100,000,000 than $50,000,000 worth of gold.

The deposits can not be made to pay if worked on a small scale. Hydraulic or dredging in the wider and deeper gulches might possibly pay, but it is a question whether the concentration of the values on bed rock, the considerable overburden to be removed, and the scarcity of water will not greatly retard if not prohibit the future development of the Greaterville placer district.

GOLD MINING IN THE RANDSBURG QUADRANGLE, CALIFORNIA.

By Frank L. Hess.

GENERAL DESCRIPTION OF THE QUADRANGLE.

The Randsburg quadrangle is included between 35° 15′ and 35° 30′ north latitude and 117° 30′ and 117° 45′ east longitude. The town of Johannesburg, consisting of perhaps a score of houses, is almost in the center of the quadrangle, and Randsburg, with possibly 100 houses, lies a mile west. The two towns are separated by a hill between 150 and 200 feet high. Johannesburg is at the end of a branch of the Atchison, Topeka and Santa Fe Railway which joins the main line at Kramer, 28 miles south. The town is about 90 miles north and 30 miles east of Los Angeles, but the distance is 202 miles by the Santa Fe Railway; and to Rand, a station 5 miles north of Randsburg, it is 143 miles by the Southern Pacific Railroad, which has recently built a line across the quadrangle.

The area is part of the Mohave Desert and has an arid climate. The summer is long and hot, with occasional showers, the effects of which are soon lost through the strong winds and heat. The spring and fall months are often pleasant, but during the late fall, winter, and early spring there is much raw wind, which frequently is little less than a gale. Occasional light snows fall, which generally melt within a day or two. On December 20, 1909, 11 inches of snow fell at Randsburg, but in the valley on the north along the Southern Pacific Railroad there was only about 4 inches.

As would be expected from such climatic conditions, the country is dry, vegetation is scanty, and if a water level exists it has been found only in the basins into which the short periodic streams flow.

To judge from the topography of the country, a similar climate has been in existence here through a considerable length of time, for the present erosional forms have probably been shaped largely by weathering agencies similar to those now observed.

TOPOGRAPHY.

GENERAL STATEMENT.

There is much diversity in the topography of the area, owing to mountain-making and volcanic disturbances, faulting, difference in rock textures, and erosion.

The variation in altitude in the quadrangle amounts to about 3,000 feet. The lowest altitude, a little less than 2,300 feet above sea level, is about the middle of the west side. The highest point, Red Mountain, 5,270 feet above the sea, is 2 or 3 miles southeast of the center.

The main features of the topography are three mountain masses, occupying the middle, eastern, and northwestern parts of the quadrangle; a large valley lying in the area between the center and the west side; a long slope to Cuddaback Lake in the southeast; a smooth, rolling area in the south; and a long, gentle slope along the eastern three-quarters of the north side of the quadrangle.

MOUNTAINS.

The three mountain masses are ordinarily referred to as the Rand Mountains, the Lava Mountains, and the El Paso Mountains, from which the Summit Range extends easterly.

The Rand Mountains cross the edge of the quadrangle about 3 miles north of the southwest corner and run northeast 3½ miles beyond Randsburg. They rise with a gentle slope from the southeast almost or quite to the summit; but on the northwest side they drop steeply to the valley, which is 500 to 1,000 feet lower than points on the southeast side that are equally distant from the crest. Along the southwest 2 miles of the range the smooth, gentle slope from the southeast extends all the way to the summit; on the northwest side the declivity is steep and much dissected. Randsburg is situated in a valley in the Rand Mountains, about 3 miles from the northeast end. Johannesburg is located in a cut through the range, 1 mile east and a little north of Randsburg. Beyond Johannesburg the mountains do not stand so high above the surrounding country, and the actual elevation is also less. The main range extends several miles southwest of the quadrangle, gradually sinking to the general level. Nearly all the gold mines of the area, except some small placer mines, are located in this range or in a spur from it.

The Lava Mountains occupy the northern half of the east third of the quadrangle; south of the main body they swing toward the southwest and include the highest peak of the area, Red Mountain. Altogether they cover about 50 square miles, or nearly one-fourth of the quadrangle. In many places they have been sharply eroded, and though there are still some flat tops, in general traveling over them is rough and tiresome. Through much of their extent the mountains are composed of soft sandstone, clay, and tuff, overlain by lava flows and agglomerate. The washing away of the sandstone and clays beneath makes the lava break away, leaving precipitous faces. The arroyos and gulches are of the usual rough, steep forms found in dry lava-covered countries.

The Lava Mountains are connected on the northeast with other volcanic mountains, which extend to the east for many miles and include Pilot Knob, a landmark known all over this part of the desert. On the west lava débris has covered 8 or 10 square miles of country and now forms hills rising 200 to 350 feet above the surrounding valleys. When poured out, the lava ran over a hilly country, filling the valleys and flowing over the tops of the hills.

The El Paso Mountains run across the north end of the quadrangle about N. 80° E. On the west they coalesce with the south end of the Sierra Nevada and the Tehachapi Mountains. The valley along their south face, extending beyond Mohave southward toward Los Angeles, is followed by the Los Angeles aqueduct, now being constructed. The range is not simple but consists of a crooked mass, shaped somewhat like an irregular S, the upper part of which runs north to El Paso Peaks and Laurel Mountain (known to old settlers as Copper Mountain). A smaller range, known as the Summit Range, which at the east side of the quadrangle is partly covered by the lava flows, extends eastward from the lower part of the S. Just west of the quadrangle Goler Wash and an eastern tributary cut through the range.

FAULTS.

A very prominent fault follows along the south face of the mountains and crosses them about the middle of the quadrangle on the Kern-San Bernardino County line. The scarp of the fault can be seen from the south for many miles. It can be readily followed west of the quadrangle for a number of miles, and on the east it can be seen cutting across the end of the Slate Range, 20 or 25 miles away. At Garlock, about 2 miles west of the quadrangle, a large alluvial fan cut through by the fault shows a face 280 feet high (barometric measurement). From its prominence at this point the fault will be referred to as the Garlock fault.

Just within the quadrangle, near its western boundary, are two large depressions formed by the subsidence of the surface along the fault. One is about a quarter of a mile long, 600 feet wide, and 75 feet deep, and the other, half a mile east, is over a mile long, a quarter of a mile wide, and 50 to 125 feet deep. These blocks have dropped in comparatively recent years, though men who were in the country as early as 1863 state that the sinks were there at that time. The principal movement here has been downward on the south or valley side, but the movement along the fault has not been the same in all parts. At a number of places between these sinks and the point at which the fault crosses the summit the latest movement has been upward on the south side.

Smaller faults are innumerable, and on the northwest side of the Rand Mountains they may have had considerable to do with making the topography much rougher than that of the southeast side.

SLOPES AND VALLEYS.

The broad, gentle slope and the sandy valley to which the Rand Mountains sharply descend on the northwest side are striking features of the quadrangle. A surprising fact is that the slope is not everywhere deeply covered with débris. The débris in many places is shallow, and outcrops of solid rock occur here and there.

The large gently rolling area in the southern part of the quadrangle is entirely underlain by granite for several miles from the south side. The mass is somewhat wedge-shaped and in the middle is about 6 miles broad from north to south. Granite crops out in all the small rises and on the slope 2 miles south of Sidney Peak. At the point of the wedge the granite reaches within $2\frac{1}{2}$ miles of Johannesburg. There are no deep watercourses across it, and the covering of débris is gradually finer at points successively farther from the hills. That the flats are very old is shown by the fact that 2 miles or more from the hills the low rounded eminences between the shallow watercourses are nearly covered with white quartz. The other rocks have decomposed and have been carried away by the occasional rain storms. The slope has evidently formed through the weathering of the rocks. On the more exposed surfaces the material has probably been largely removed by the wind, which carries the finer particles into the valleys, while the coarser particles are rolled to the foot of the sharper slopes.

The slope at the north end of the quadrangle is similar, except that it is heavily covered with débris, owing to the shattering of the rocks in the Summit Range adjacent to the Garlock fault and their subsequent conveyance down by water, and to the accumulation of material from a soft sandstone which at one time covered part or all of the area.

The valley north and west of Randsburg, lying between the Rand and El Paso mountains, is a fault valley and is deeply filled with débris. By far the longer slope is on the Rand Mountains side. For a mile or more from the base of the main mountain slope bed rock is exposed here and there, but farther away the rocks are entirely covered by the accumulated débris, which becomes gradually finer toward the middle of the valley. In the western part of the quadrangle south of a line one-half mile south of the Summit Range there is a belt of fine soft sand 2 miles wide. The valley is not symmetrical, owing to the fault on the north, which has let the valley floor down on that side in the western part. The upper part of the valley, above the point where the fault leaves it, shows no extraordinary development.

GEOLOGY.

The rocks of the quadrangle show considerable variety, but though two or three of the igneous rocks have rather exceptional structure there are no remarkably unusual types. Granite occupies the surface of nearly five-tenths of the quadrangle, lava over two-tenths, schists over one-tenth, partly metamorphosed limestones and other sediments less than one-tenth, and sand, with other unconsolidated fragmental covering, less than one-tenth.

GRANITES.

The two main granite areas have already been roughly outlined, one being a broad, wedge-shaped area in the south end of the quadrangle, with the apex about 2½ miles south of Johannesburg, and another extending from the Summit Range northward east of El Paso Peak to the edge of the quadrangle. There is also an intrusive granite which cuts across the Rand Mountains on the south side of Randsburg. It is about 4 miles long and one-half mile wide, forming four of the more prominent peaks. A part of this intrusion is so mixed with schist that it can be mapped only as a complex. This intrusive mass is probably younger than the large mass to the south, for the latter seems to be under and may be older than the schists of the Rand Mountains, whereas the granitic intrusion near Randsburg cuts the schist and probably the granite on the south. It has many phases and in places is basic. There are certain dikes which are orbicular diorites. These dikes have a black and white groundmass of basic feldspar and biotite mica, with round segregations containing a much larger proportion of biotite and small porphyritic feldspars. The segregations or orbicules range from 2 to 18 inches in diameter, but are mostly less than 6 inches. In places the orbicules are round and in other places lens-shaped. Between Caliente and Keene, 40 to 45 miles west of Randsburg, similar dikes, with the orbicules pressed into flat lenticles whose longest diameter is as much as ten times the shortest, appear at numerous places along the road.

The granite at Randsburg was not all intruded at one time, but the periods between the successive intrusions were very short, geologically. During the same period of time in which the granite was intruded many narrow porphyritic dikes of various compositions and textures were intruded. Some of the more acidic ones cut the granites and diabase dikes. In other places they are cut by the granite and by the diabase. At one place on the mountain south of Randsburg porphyritic fragments are cemented by a granitic rock, and on the west side of Red Mountain a granitic dike contains so many large porphyritic fragments that in some places it is difficult to tell which rock forms the dike and which are the inclusions.

Besides the intrusive rocks mentioned, there are near the old Hardcash mine on the northwest side of the Rand Mountains, between 3 and 4 miles southwest of Randsburg, greenstones in masses several hundred feet across. Other greenstones occur on the northwestern edge of the quadrangle, north of Goler. The granites in the northern and northeastern parts of the quadrangle are cut by basic dikes, generally only 2 or 3 feet wide.

SEDIMENTARY ROCKS.

The sedimentary rocks include the schists of the Rand Mountains, the less altered rocks in the northwestern corner of the quadrangle, and a much younger series of poorly consolidated sandstones and clays which crop out from under the lavas and which are also found at Summit Diggings and near the northwest corner of the quadrangle. The rocks of the Rand Mountains are mostly schists with minor interbedded quartzites and greatly altered limestones.

On the southeast side of the mountains and around Randsburg and Johannesburg the schists are thinly fissile and of a dull-gray color. They may be classed as mica-albite schists. The albite is in small knots, generally white and less than one-eighth inch across, but in many places contains so much graphitic matter that it appears black.

On the northwest side of the mountains the schists have, in general, a chloritic appearance, the albite crystals are larger, and the schist is coarser. They are probably lower stratigraphically than the gray mica-albite schists. In places there are beds of amphibolite schist, both light and dark, and some talc schist. The amphibolites are probably altered basic intrusive rocks. In many places the schists have low dips of 5° to 30°, but locally they stand on edge. The schists are so much faulted that an accurate estimate of their thickness can not be made. However, it is probably over 1,000 feet. The schistosity agrees with the bedding.

Interbedded with the schists are strata of pinkish or brown quartzite 6 inches to 6 feet thick, which, in places, show schistosity. In other places the quartzite contains manganese carbonate (on the Cock Robin claim 2½ miles south of Johannesburg) and manganese dioxide (5 miles southwest of Randsburg).

In a small valley 1 mile southwest of Randsburg, on the northeast part of the mountain between Randsburg and the valley, on the north side of the 4,150-foot mountain east of Randsburg and south of Johannesburg, and at other places, limestone 3 to 12 feet thick is found in close connection with the schists. Limestone is present also along the granite contact, under the schist south of the Blackhawk mine, and along the contact south of the Sidney mine. This may be in each place the same limestone, but it is less metamorphosed in most places along the southern border. The limestone is highly crystalline and shows no fossils.

Two miles north of Randsburg are gneissoid rocks, composed largely of white feldspar and chlorite, but not yet examined in detail, between which and the schists no break can be observed. On the other hand, no definite gradation can be observed between them and the more finely schistose rocks of the Rand Mountains, and until more data are at hand they will be considered as a coarser and probably a lower part of the schists.

Little is known of the age of the schists, and no schists similar to those of the Rand Mountains are known within many miles in any direction. So far as present knowledge goes, they form an island in a sea of residual sand. Inquiries were made of numerous prospectors acquainted with other portions of the adjacent desert, but none had seen or at least none had recognized the schists in other places. Prospectors are ordinarily very observant men, and in such a case as this would be sure to notice the fact if similar schists were seen in other localities, owing to the occurrence of gold within the Randsburg area.

The sediments in the northwest part of the quadrangle consist of quartzite, mostly very fine grained, but with a few beds of coarser material; siliceous shales; and limestones, most of which contain a considerable amount of impurities. The limestones contain much chert and in places are so siliceous that little calcium carbonate is to be seen. One bed of limestone is stained red with oxide of iron, so that it is noticeable for a long distance. This particular limestone is thinly bedded and probably about 200 feet thick. Other beds are from a few feet to 100 feet thick. The entire series is probably several thousand feet thick, but owing to folding and faulting it is so difficult to measure that probably no reliable figures could be obtained even in much greater time than was at the writer's disposal. The general strike of the rocks is about northwest, with dips largely to the northeast. A few of the beds are schistose, but they bear little resemblance to the schists around Randsburg.

Only two specimens resembling fossils were found. They were very indistinct, and the better one George H. Girty believes to be possibly a Paleozoic coral or sponge and probably not younger than Carboniferous. These are the only fossils found in the quadrangle.

The sediments of the El Paso Range can probably be connected with other sediments along the Sierra Nevada when the work of correlation is taken up in the field.

A mile and a half southeast of Johannesburg, on the west side of the railroad, is an outcrop of a coarse, very friable yellow sandstone, composed largely of small fragments of quartz, and larger pieces of granite which range up to 3 or 4 inches in diameter. The quartz particles are evidently from granite and are not well rounded. The large pebbles are mostly of pink granite, such as is found in the quadrangle only near the southern edge, a little west of the center, and are only fairly well rounded.

The sandstone has been lifted and then broken through by the lavas of Red Mountain, so that it forms an irregular border around the mountain. Beds of gray, buff, brown, and red unconsolidated clay occur interbedded with the sandstone, and at one place on the northwestern side of the mountain an 8-inch bed of gypsum is included. A mile and a half northeast of Skilling well a bed of gray, impure limestone, which seems to be in lenticular masses reaching 3 to 4 feet in thickness, is interbedded with the sandstone. The limestone has a peculiar nodular structure, like an augen gneiss, as if made up of small lenticles, 3 or 4 inches long by 1½ inches thick. In weathering it leaves nodular pebbles an inch thick. Seven miles northeast of Johannesburg the sandstone forms a sharp yellowish-green peak. At Summit Diggings and in a hill three-fourths of a mile southeast of the Skilling well the sandstone has been changed to a quartzite by intrusive igneous rocks. In some places tuffs form the upper portion of the sandstone.

The sandstone is deposited upon the schists and granite and can be seen in contact with them 3 miles north of Johannesburg. That there was igneous activity during the deposition of the sandstone is shown by the tuff beds at the top. These are made up largely of fragments of pumice, probably rhyolitic, an inch or more in diameter.

The sandstone is probably a brackish-lake deposit and is to be correlated with similar deposits in other parts of the desert which are believed to be Tertiary.

LAVAS.

The lavas are largely andesites, with some basalt, but include more acidic varieties, rhyolite, and probably latite and dacite. There is some obsidian among them. Five miles northeast of Johannesburg fragments of the coarse basal part of the schists are included in the lava, showing that it must have broken through the schists. Fragments of the sandstone also form inclusions. In places there are large masses of broken lava solidly cemented, which, here and there, are colored purple and bright green.

FRAGMENTAL DEPOSITS.

The fragmental deposits, such as sand and gravel, cover considerable areas. As in many arid countries, the lack of streams to grind up and remove them makes the accumulations large, and the valleys are in some places deeply filled with débris. About 2 miles east of St. Elmo a shaft was sunk 250 feet without striking bed rock, though there is a granite outcrop halfway between St. Elmo and the shaft. In a low range of hills 2 miles north of Randsburg, in the small valleys tributary to the large one, shafts have been sunk more than 100 feet deep without striking bed rock, though it shows in the low hills on either side. Small valleys have been entirely filled and the hills on either side covered. At Goler the gravels are at least 800 feet deep, as shown by wells drilled by the Yellow Aster Mining and Milling Company.

On the north side of the valley between Randsburg and Goler there is a very large accumulation of débris, forming hills over 350 feet high. They extend halfway across the quadrangle to Summit Diggings. In them is a great quantity of lava bowlders, remnants of flows from Black Mountain, a few miles west of the north end of the quadrangle. The lava bowlders occur in patches over the summit of the El Paso Range. With the lava is a gravel foreign to the quadrangle, composed of well-rounded quartzite, granite, and intrusive rocks. Its origin has not been traced but seems to have been somewhere in the Sierra Nevada. A group of low hills over 2 miles in diameter north of the northeast end of the Rand Mountains is covered with lava débris from the east side of the quadrangle, and this débris also extends over the low hills 2 miles north of Randsburg. Only a small area of gravels, those located at Summit Diggings, are of economic importance.

HISTORY AND PRESENT CONDITION OF MINING.

Gold was discovered in Goler Wash, 9 miles northwest of Randsburg and a little west of the quadrangle, in the winter of 1893–94. Dry-washing camps soon sprang up there and in Last Chance Canyon, Red Rock Canyon, and Summit Diggings. The site of the last-named camp is in the quadrangle.

In 1895 the Yellow Aster mine was discovered by C. A. Burcham, John Singleton, and Fred Mooers, and other discoveries quickly followed. A railroad was soon constructed from Kramer. on the

Atchison, Topeka and Santa Fe Railway, to Johannesburg, and water was piped from wells 6 and 8 miles east and northwest.

At present there are possibly 700 people in the entire district. The Yellow Aster has been and still is the main mine of the quadrangle. A number of mines, after taking out fair ores near the surface, were unable to follow them downward owing to faulting, pinching of the veins, or impoverishment of the ores, and have been abandoned.

The mines, including the dry placers, have probably produced between $9,000,000 and $10,000,000, of which the Yellow Aster mine has taken out about $6,000,000.

During 1908 the mines of the quadrangle produced $656,560 in gold and $5,321 worth of silver.[a] All the silver was contained in gold bullion. Not counting impurities, these figures indicate a bullion fineness of about 751. The bullion of the Yellow Aster mine averages about 790 fine.[b]

A number of the smaller mines are worked by the leasing system, paying from 10 to 25 per cent royalty, generally after deducting milling charges, but sometimes gross. Twenty-five per cent royalty is probably in each case more than should be paid, and makes mining too hazardous for the lessee. It is usually paid where a lessee has made a fair profit at lower royalty and someone else, desiring to get the same lease, offers a larger one. The owner is then apt to demand a still higher royalty, to the loss of the lessee.

Besides the Yellow Aster's stamp mills, with 100 and 30 stamps, there are the Phoenix, 6 stamps; Red Dog, 10 stamps; Sunshine, 3 stamps; Ostick & Renne, 3 stamps; Blackhawk, 10 stamps; and Little Butte, 2 stamps. The last two are not operated. All of these work on custom ores except the Yellow Aster and Sunshine mills, which work only ores from their own mines. The Atolia Mining Company has a 5-foot Huntingdon mill which is used only upon scheelite ores.

Half a dozen men still work in the placers, making slender "grub money."

In what is known as the Rademacher district, which includes El Paso Peaks, Laurel Mountain, and the adjacent country on the north, considerable prospecting has been done for a number of years and a little is still carried on, but there has been no output.

GOLD DEPOSITS.

DISTRIBUTION.

Most of the gold deposits of the quadrangle lie in the schist area, along the Rand Mountains, reaching their greatest development in the Yellow Aster mine at a place where a granitic intrusion crosses the

[a] Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 336.

[b] Burcham, C. A., president Yellow Aster Mining Co., in letter dated April 21, 1910.

axis of the range. Along both sides of the range, southwest from Randsburg, are other gold deposits, but those on the northwest side of the range have so far produced very little ore. On the southeast side of the range a number of mines have been and are being profitably worked. There are also a number of mines in the schists within a radius of 1½ miles north and east of Randsburg.

Outside of the schists of the Rand Mountains the St. Elmo mine, located in the granite 5½ miles southeast of Randsburg, has produced some gold. Six miles north by east of Randsburg, at Summit Diggings, a few thousand dollars has been taken from gravels in the sandstones surrounding an intrusive mass of hypersthene-hornblende andesite which has locally metamorphosed the sandstone into quartzite. No veins have been found in the vicinity. Three miles northeast of Summit Diggings, on the north side of the Summit Range, veins an inch or so wide have been discovered which carry gold, silver, and copper, but there has been no production from them.

On the north side of El Paso Peaks and on the north and northeast sides of Laurel Mountain a little gold has been found in narrow veins with copper minerals, but no ore has been produced. Scheelite occurs in small amount with the gold ores in a number of the mines in the Rand Mountains, and a mile north of St. Elmo, at Atolia, are mines which are probably working the largest and purest scheelite deposits known.

YELLOW ASTER MINE.

GENERAL DESCRIPTION.

The Yellow Aster was the first "hard-rock" gold mine discovered in the quadrangle, and for ten years it has been one of the largest gold producers in California. It is at the head of a gulch running northeast from a peak at the northeast end of the main body of the Rand Mountains, a little over one-half mile northeast of Government Peak. A crescent-shaped mass of granite, described on page 27, here cuts across the mountains.

The principal level of the underground workings, known as the Rand level, is about 500 feet below the top of the mountain. The Glory Hole, from which practically all of the ore mined was being taken at the end of 1909, opens from the gulch 105 feet above the Rand level. The granite is intrusive in the schists and occurs in many dikes, which show a close relationship petrographically, though there is a wide difference in their general appearance as casually examined, owing to their varying degrees of decay and alteration. The granite in the mine carries biotite and is rather fine textured. In places the biotite forms irregular segregations from one-fourth inch to 2 inches in diameter. The feldspars are white, buff, and pink, and in some places where the granite is fine grained there are small porphyritic white orthoclase feldspar crystals one-eighth to one-fourth inch in thickness. In places some hornblende has evidently been contained in the granite, its former presence being indicated by aggregations of small particles of magnetite whose general outline corresponds to a cross section of hornblende.

There are also porphyry dikes cutting both granite and schist, but they are older than the ore bodies, which pass through them. Where found in the mine, the granite porphyries are light colored and show little or no mica or hornblende, though it is probable that the lack of biotite is due to its decomposition. The groundmass is of fine-grained orthoclase. The phenocrysts are of microcline and orthoclase with here and there a small quantity of lime feldspar. The phenocrysts are generally not over one-eighth inch in diameter. The granite masses range in thickness from a few inches to several hundred feet. They are evidently branches from a larger body and may come together below.

The prevailing dip of the schists on the top of the mountain is nearly flat, but locally the schists lie at all angles and dip in many directions. Similar variations of dip and strike are seen in the mine. The schist is thinly fissile except near the larger granite masses, where it is locally so compact that it is difficult to distinguish from a dark granite. This appearance has given rise to a belief that the schists are crushed igneous rocks.

At a few places the schists are very siliceous and have probably been formed from quartzose sediments. The schist carries much mica and feldspar, which show that the original sediments contained a considerable quantity of clay.

There is a noticeable absence of visible quartz in the mine. In many places the schists contain large lenses of white quartz, but it is practically barren, and in the few places where massive quartz is found in the mine it does not carry values.

ORE BODIES.

GENERAL TYPES.

The gold deposits found in the Yellow Aster mine are typical of those found in many other mines of the vicinity and will, therefore, be described in some detail.

There are three types of gold-bearing ore bodies in the Yellow Aster mine:

1. Deposits along faults in crushed schist and granite.
2. Stockworks in granite.
3. Fissure veins, with more or less quartz.

In only two or three other mines of the area is there more than one type of gold deposit, and no other has all three types. The three types, though distinct for the most part, in places grade into each other. Very little visible gold is found in the mine, and that little is mostly in small particles. There is a remarkable lack of other metallic minerals. A little pyrite and arsenopyrite, iron oxide derived from them, and some scheelite are the only ones certainly identified, though it is reported that some pannings show a heavy mineral of a light-yellow color which may be wulfenite. Quartz is present in noticeably small quantity. There is some calcite in the veins, which crystallizes in peculiar flattened forms.

FAULT LODES.

The faults were probably caused by the stresses accompanying the intrusion of the granite. They are probably nearly all normal or gravity faults, but the amount of movement is not known in any ore-bearing lode. The movement has been, in each fault, in different directions at different periods, and these directions vary from vertical to horizontal.

On the Rand level the main fault is followed by the Jupiter drift, running N. 80° W., with many minor curves and variations in its course. The fault will hereafter be called the Jupiter fault. The gulch cuts through the fault at the Rand level, where the fault turns and runs about S. 70° E. The dip is from 27° 30′ to 44° to the north and east, but it is less toward the bottom of the workings, 300 feet below the Rand level. The dip is wavy, as is the strike of the fault.

The fault is slickensided in many places on both sides, and accompanied by crushed material from 2 to 80 feet thick. The greatest thickness is in the 100-foot level. The rock is not all crushed fine, but the fault branches with finely crushed material along each part, and the rock between the lesser faults is badly broken. The fault cuts both schist and granite. In both rocks the comminuted material along the fault is so fine and decomposed that in many places it is almost impossible, without much work and careful observation, to tell whether the material is schist or granite.

As would be expected, especially when the diverse movements that have taken place are considered, there is great shattering of the rocks and many minor faults with much slickensiding where the fault turns. Probably the deep gulch at the particular point where the mine is located is due to the shattering caused by the change of direction in the fault.

A great deal of work has been done along the fault. Various levels and stopes follow it to the top of the mountain, and below the Rand level four levels were worked. The amount of ore extracted decreased as the depth increased, and little was done on the Fourth level. Below the Third level the quantity of crushed material along the fault decreases considerably, iron and arsenic pyrites appear, and gold values decrease.

Below the Rand level large chambers were taken out in granite lying in the fault zone. One square-set stope on the first (100-foot) level was over 100 feet long, 50 feet wide, and probably 40 feet high. The gold in this stope is said to have been coarse, in places reaching the size of wheat grains. The ore is thought to have averaged $10 per ton.

Above the stope a sill of granite has been forced between the folia of the schist, which here has a dip of 30° NE., and part of the sill has been taken out for ore. Where the granite is ore bearing it is soft, the biotite is bleached, and the feldspars are sericitized.

Masses of granite have been mined in the Second and Third levels, which are probably part of the same body that was mined in the First level. The workings on the Fourth level were filled with débris and could not be entered, but a small square-set stope is reported to have been taken out of granite.

Near the top, on the northwest side of the hill, several other faults, approximately parallel in strike to the northwest limb of the Jupiter fault but with different dips, have been followed by the workings. Their differing dips cause them to coalesce, and they are probably joined to the Jupiter fault. On the southeast side of the gulch a considerable amount of work has been done along the Jupiter fault. The latter work was done a number of years ago and is now largely caved.

Two other fault zones have also been worked on the southeast side. One, which will be called the K. P. fault, from the name of a stope along it, is about 300 feet southwest from the Jupiter fault. It strikes northwest and dips at various angles. Near its junction on the northwest with a large shattered granite mass the dip is about 30° NE. Toward the southeast the dip steepens nearly to 60°. Some ore has been taken out along its course, but it has not been a large producer.

About 75 feet farther southwest is another fault which will be referred to as the Oriental, from the name of the drift following it on the Rand level. In its general strike the Oriental fault is nearly parallel to the Jupiter fault south of the gulch, and the dip is in the same direction. It has been followed for over 1,000 feet, and at the southern end it is very irregular in direction, is split up, and shows signs of either changing its direction or dissipating into a number of small faults. A stull stope 5 to 18 feet high, reaching nearly to the surface, has been taken out along it.

What the ore has averaged is unknown, but part of it has been of low tenor—less than $2 per ton. It is probable that the ore lies in lenses in the crushed fault zone, as in other mines working similar lodes, and that much of the rock taken out carries practically nothing.

STOCKWORKS IN GRANITE.

The second type of ore deposit in the Yellow Aster mine is made up of comparatively large bodies of granite, which are shattered and impregnated with gold along narrow cracks forming complicated reticulations or stockworks.

The biotite of the granite has been bleached and the feldspar is considerably decayed. Gold is not found in paying quantity where the granite is not largely decomposed, but on the other hand there is no assurance of gold where the granite is decayed. In the lower levels, where oxidation is not so far advanced, there is a considerable amount of arsenopyrite in the rock, and in some drifts the garlic-like odor of oxidizing arsenic is noticeable.

On the Rand level two large square-set stopes, the East sets and the West sets, have been taken out from stockworks. They lie about 500 feet southwest (into the hill) from the point where the Jupiter fault crosses the gulch and almost form a chord to the crescentic fault.

The East sets have a length of about 265 feet and a maximum width of 95 feet and are said to be 50 or 60 feet high. They have a strike between N. 75° W. and N. 80° W. The sets have largely been filled with waste, so that the upper sets are not accessible, and the mine maps show no cross sections.

The West sets are 340 feet long, have a maximum width of 50 feet, and reach upward to the bottom of the Glory Hole, 105 feet, and strike nearly northwest.

The two stopes are in the same mass of granite, 150 feet of which lies between them. It is said to be a low-grade ore.

The West sets are roughly parallel to that part of the Jupiter fault which is southeast of the gulch and the East sets are more nearly parallel to the part northwest of the gulch.

Below the Rand level large square-set stopes which extend to the First level have been taken out in the granite mass. They are not so large as the stopes in the granite on the Rand level.

Strong faults with a stiff clay gouge bound the northeast side of the granite in the West sets and dip 45° to 50° NE. In places the gouge is damp, possibly from leakage of water in the open cut above. The Nero stope, which extends from the Rand level to the First level, follows the fault.

It is not known just what the value of the ore taken from the stopes in the granite has been, but it is believed to have been from $4 to $5 per ton in the East and West sets and probably about the same in the other stopes. There have been places where the values were considerably greater, but the figures given are probably near the average values.

On the Second level only comparatively small stopes have been taken out in the granite, and on this level the stoping is along a fault dipping 50° N. 27° W., the ore lying both above and below the fault. The strike and dip of the fault are probably local, and it seems likely that the general direction of dip is N. 20° to 45° E.

Stopes in the granite have been taken out in the 70-foot and Trilby levels, 53 and 105 feet, respectively, above the Rand level, but they are not so large as the East and West sets. The granite is said to have been worked also in a still higher level, which is now caved and can not be entered. Near the top of the hill some work has been done in shattered granite, but compared with that described it is not extensive.

FISSURE VEINS.

Lying within the curve of the crescent-shaped Jupiter vein, between it and the granite, are two nearly vertical veins known as the Jake Price and the Rand Vertical veins, striking about northwest. On the 100-foot level they are 65 to 110 feet apart, the Jake Price being the nearer to the Jupiter fault, from which it is about 220 feet distant. On the Rand level there is little to be seen of the Jake Price vein. Above the First level the two veins lean toward each other so that they are only a few feet apart at the Rand level.

The Rand Vertical vein runs above the Rand level and joins with the Jupiter fault. At the junction and above it some rich ore has been taken out. The veins have been stoped continuously from a point below the 200-foot level to the Rand level, and the Rand Vertical for perhaps 50 feet above to the Jupiter fault.

Both of the veins are in narrow shear zones that lie mostly in granite dikes but also cut the schist. The cracks of the zone are considerably iron-stained, but no other mineralization is visible. There is some bleaching of biotite through several feet of granite along the vein.

Parts of the veins have been rich, yielding ore reported to be worth over $100 per ton.

The Rand Vertical, below the Second level, follows a granite dike and has been followed downward by a shaft for more than 150 feet. In many places the dike is only 3 or 4 feet thick, and at the depth mentioned it dips into the wall to the north. An attempt to find it by a crosscut 50 feet below was unsuccessful.

Several other fissure veins similar to the Rand Vertical and Jake Price are exposed in the Glory Hole. The richest of these strikes N. 32° W. and is vertical. Others are said to be approximately parallel to this one, but they could not be identified. This vein differs from those described in that it carries up to 3 inches of impure quartz, which in places shows visible gold. The quartz is by no means continuous, even where the vein contains good values in gold. The veins cut both granite and schist.

Another vein that is similar but contains little quartz occurs in a drift running southeast from the Jupiter drift on the Rand level. The vein is in fact merely a series of cracks formed by a shear zone and shows little or no silicification. The cracks cut through a white granite porphyry dike, but the zone is somewhat narrower in the dike, owing to the great resistance of that rock to shattering. No instance of a dike cutting the ore is known in the mine, but in a number of places the ore cuts through dikes, always with much less mineralization, owing to the greater freshness and hardness of the dike matter.

MINING.

There are estimated to be between 12 and 15 miles of drifts, tunnels, and shafts in the Yellow Aster mine, but at present practically all the work is being done in the Glory Hole, and it is the intention to work the mine hereafter entirely by open-cut methods. The grade of the ore mined is thus reduced, but it is estimated that it can be kept high enough to yield a profit. A tremendous amount of overburden must be removed and much nearly barren material must be milled, but the cost of mining is low.

OTHER MINES OF THE FAULT-LODE TYPE.

Across the valley, northeast from the Yellow Aster mine, are four mines located upon a fault that strikes northwest and dips 30° to 75° NE., with many local variations in dip and strike. A diabase dike, from 15 to 40 feet wide and a little more than a mile and a half long, runs along the course followed by the fault. In some places it is cut by the fault; in others sills from the main dike run along the fault, and the fault shows that movement has taken place along it since the intrusion. The diabase both cuts and is cut by granite porphyry dikes. It is, therefore, contemporaneous with the porphyritic intrusions and with the faulting, having been later than the first breaking of the fault, but movement in the fault continued after the intrusion of the diabase.

The gold deposits of the mines along this fault belong to the fault-lode type. From northwest to southeast the mines along the fault are the Little Butte, credited with an output of $35,000, and now unworked; the Kenyon, or "400;" the Butte Wedge, which, in conjunction with the Kenyon, is reported to have produced $500,000; and the Butte, reported to have produced $525,000. Still southwest of the Butte are the Philadelphia Wedge, Jenny Lind fraction, Hector, and Magpie claims. Some ore is said to have been taken from each of these.

There is somewhat more quartz in the fault matter in these mines than in the Yellow Aster. The distribution of values is exceedingly erratic and the ore is ordinarily in lenses, which may be either rich or poor, large or small. One lens in the Kenyon was 10 feet thick and averaged $100 to the ton. It was 40 to 50 feet wide. Other lenses are only a few inches thick and a few feet long. The material on either side, so far as can be told by the eye, may be precisely similar but almost or totally valueless. To show how erratically the ore occurs, Percy C. McMahon stated that although over half a million dollars in gold had been taken out of the Butte in the twelve years he had been connected with the mine he had never seen over $5,000 worth of ore in sight at one time. This was not due to lack of development, for hundreds of feet of drifting and exploratory work had been done, but to the distribution of the values in irregular and almost isolated lenses. At a depth of 520 feet along the incline, or a vertical depth of probably about 300 feet, a good shoot of ore was struck 450 feet northwest of the shaft and was stoped out to the 400-foot level, giving from $35 to $87 in gold to the ton. At this depth the crushed fault material is 1½ to 2 feet thick and carries pyrite and arsenopyrite.

A rich stringer of ore found 300 feet southeast of the shaft cut across the fault and carried $200 to $300 a ton. Only about $1,200 was obtained from it.

It is very probable that there is a similar distribution of the gold in irregularly sized lenses in the Yellow Aster fault lodes, but the system of mining on a large scale and of assaying from the bulk mined does not show it so plainly.

A mile directly north of Randsburg and also 1½ miles north, C. E. and J. Jeffords have mined upon similar faults. On the claim nearer Randsburg, known as the American, the principal workings are on a fault striking N. 20° to 30° W. and dipping about 40° E. The claim farther north and others in the vicinity are in comparatively flat ground known as the Pumpkin Patch and are all along similar faults. They have produced a few thousand dollars in gold, but none are now being worked, as the paying ore near the surface was soon taken out.

At Johannesburg the Phoenix (formerly known as the Val Verde) and the Pinmore or Penimore are working upon fault lodes similar to those of the Butte and Yellow Aster. In the Phoenix both diabase and granite porphyry dikes have been intruded along the fault. The granite porphyry dikes have been greatly squeezed. The diabase dikes are less disturbed and are evidently later.

In the Pinmore the faulting is very complicated. The mine is partly caved, and there are no maps, so that the system of faulting was not solved. Southeast and south of Randsburg the Rattlesnake, Gold Bug (or, as it is generally referred to, the G. B.), Baltic, Blackhawk, Gold Coin, California, Nancy Hanks, Big Horse, Josephine T. G., Golden Link, Hard Cash, and some others are located on similar faults and have produced more or less gold. In the Baltic ores said to carry about $7 a ton were taken out in one stope, which was 24 feet high and 60 to 70 feet broad. Scheelite is said to show in most of the pannings from the mine, and a ton was taken out in one place. It is also found in the G. B. and other claims. The Gold Coin has fissure veins besides fault lodes and will be referred to later. The Hard Cash is on the southwest side of the mountains and unsuccessfully attempted a dry-separation process.

The lode on the Buckboard claim, 2½ miles in a direct line west by south of Randsburg, may be classed with the fault-lode type of deposits, though it shows characteristics of the fissure-vein type. The deposit is along a fault with a dip varying from nearly flat to 35° N. 40° E. The fault is smoothly slickened in places, and the striæ form a downward-opening angle of 15° to 45° southwest of the dip. A fine-grained light-colored dike, with no porphyritic crystals, follows the fault so far as exposed on the upper side of the vein matter. The dike, though somewhat broken, is not much crushed. In places it is 4 feet thick and at other places pinches out. A small, more basic dike shows in a few places.

The vein matter is quartz, and apparently it replaces the schist crushed by the fault. The quartz is everywhere impure and porous, but in general is comparatively white. At one place about 200 feet down the incline from the mouth of the shaft the vein is 15 feet thick. In other places it pinches or degenerates into mere stringers in the schists. There are many small pseudomorphs of hematite after pyrite or arsenopyrite; it is not clear which, but probably both are replaced. The inclined shaft follows the fault about 300 feet. Near the bottom the vein is smaller and less oxidized, and arsenopyrite is sprinkled through the crushed material.

In the ore on the dump a piece from an albite feldspar vein 2 inches thick was picked up. While this was not found in place and it has schist on both sides, it seems to indicate a relation between the lode and the fissure veins of the Stringer district. The albite is totally different from the dikes along the lode or in the vicinity.

A thousand tons of ore from the Buckboard was hauled to Johannesburg for milling tests and is reported to have run $6 a ton.

OTHER GOLD DEPOSITS OF THE STOCKWORK TYPE.

The only gold deposits of the stockwork type in the quadrangle besides those of the Yellow Aster mine are on claims adjoining the Yellow Aster properties on the northwest. So far very little or no ore has been taken from them. The granite is said to carry $4 or $5 per ton. To pay, it would have to be worked on a large scale; and as water would have to be obtained—a very expensive undertaking—

with the present showing it probably would not pay. Some good ore is reported to have been taken, in the early days of the camp, from similar deposits on claims lying about three-fourths of a mile west of the Yellow Aster.

OTHER GOLD DEPOSITS OF THE FISSURE-VEIN TYPE.

The mines of the quadrangle which work fissure veins are located in what is known as the Stringer district, along the southeastern side of the Rand Mountains, from 1½ miles south to 4½ miles southwest of Randsburg. They are comparatively small mines, working veins which, though generally narrow, are in places rich. The district receives its name from the narrowness of the veins.

SUNSHINE-LA CROSSE VEIN.

The vein upon which the Sunshine and La Crosse mines are located is probably the best known and will serve as an example. The mines are 1½ miles south of Randsburg. The Sunshine is on the south side of a shallow valley and the La Crosse is a few hundred feet west, on a small hill. The vein strikes from N. 80° E. to east and west and is practically vertical. It is said to dip 5 feet south of the vertical in a depth of 450 feet. The country rock is gray mica-albite schist, which strikes N. 10° E. and dips 70° to 80° E. The vein is in places as much as 8 or 10 inches thick, but is ordinarily less. From 2 to 6 inches may probably be set down as the average thickness. It is comby; that is, quartz crystals have grown from the sides and the combs have grown together and interlocked until the vein is nearly solid. In only a few places are there vugs in which the quartz crystals retain their individuality. The crystals are in most places very slender, not over one-eighth inch in diameter by an inch or more in length. A very few stout crystals in which the diameter approached the length were seen. Gold is visible in the vein in many places, and is either alone or intergrown with small crystals of arsenopyrite, with intergrowths of arsenopyrite and galena, probably arsenopyrite and zinc blende, arsenopyrite and chalcopyrite, and possibly arsenopyrite and some other mineral. The mineral masses are almost all under one-eighth inch in diameter, and at no place do they form any considerable part of the vein. Each of the minerals occurs alone, as well as intergrown with others. Traces of tellurium were identified in the ore by Chase Palmer, of the United States Geological Survey, but no tellurium mineral has so far been identified. Commercial chemists have also reported tellurium in the ore. Small hairlike crystals of rutile have been found in the vein at one point.

The largest aggregates of gold seen in the quadrangle were taken from the 350-foot level of the Sunshine mine. Two pieces, thought to weigh about 3 ounces each, were made up of small crystals of gold.

The individual crystals were from one thirty-second to one-sixteenth of an inch in diameter. In one piece part of the crystals show one pyramid of an octahedron; others have the edges of the pyramid truncated; others appear to be a cube attached by one corner with the diagonal corner truncated; still others are flattened into plates three-eighths of an inch broad by one thirty-second of an inch thick. All are striated. In the second aggregate the crystals appear round at a casual glance, but are made up of minute plates, much striated.

The minerals enumerated are plainly original in the vein. On the 350-foot level there is a little pyrite which is probably secondary and has been formed from the breaking down of the arsenopyrite. It may also occur on other levels, but none above the 300-foot level could be examined. The vein has been stoped from the 400-foot level (which is said to be really 425 feet) to the surface, though not through its whole length. Some parts of the vein were too poor to work, but they formed the lesser part. Such a barren place was found 175 feet east of the shaft, but it was only 14 feet wide along the vein, and after this was passed the values were found as before.

It is estimated by the lessees that to be profitable the vein must carry $25 in gold per ton and be 6 inches wide. As much of the vein is only 2 or 3 inches wide, it must carry much more than $25 in gold per ton.

The total length of the vein, as shown by the workings in November, 1909, was about 500 feet. At the west end it pinched just east of the La Crosse shaft. On the east end it is cut off by a fault, beyond which it has not been traced.

The vein is crossed by a number of faults which offset it a short distance and by others which, as far as prospecting at that time showed, cut it off completely at both ends. On the west end it is cut off 57 feet from the shaft on the 400-foot level by a fault dipping about 50° SE. The direction of movement could not be ascertained. The vein strikes N. 75° E. at this point. On the east side, 230 feet from the shaft, in the 400-foot level, the vein is crossed by a smaller vein carrying very low values, running north-south, which pinched within 10 feet to the south. The cross vein followed a vertical fault zone. No effort has been made to find the main vein on the opposite side of the fault. The vein was being prospected by deepening the shaft at the time it was visited (the first part of November, 1909) and it was reported that the vein was cut off below the 400-foot level, probably by the same fault that cuts it off on the west. The vein itself crosses a number of faults, which show as much as 6 or 8 inches of crushed materials.

OTHER VEINS IN STRINGER DISTRICT.

Other veins of the same type occur in the Stringer district on the Winnie, Napoleon, Santa Ana, Pearl Wedge, Merced, Royal, Corona, Sidney, Yucca Tree, Bully Boy, Golden Link, and other claims that are not worked.

The Napoleon is reported to have yielded nearly $1,000 per foot from a shaft 100 feet deep, but this seems to have been its richest part and it was not being worked when visited.

The Winnie was the first of the "stringer" claims discovered. At one place the quartz was 2 feet thick and gave $140 a ton on the plates. This was both the thickest and the richest part of the vein. Where worked in November, 1909, the vein was split into four or five branches, from 1½ to 3 inches thick and spread through 3½ to 4 feet of schist. The ore here yielded about $50 per ton on the plates. The quartz is said to show a small amount of scheelite upon panning, but the tungsten mineral is nowhere visible. On the same claim is another vein which carries scheelite and from which several tons have been taken. The characteristics of the veins are considerably different, however, and the scheelite vein carries but little gold. It is thought that the veins carrying the noticeably larger amounts of scheelite are later than the gold veins, for the following reasons: In the Gold Bug claim the scheelite occurs in small lenses in the gold ores—the scheelite itself not carrying gold—and is not so badly crushed as the gold ore. In the Sidney mine scheelite of a bright buffy color occurs in veins with gold, but it was seen only where the vein had been more or less disturbed. Gold occurs in the vein close to the scheelite, and although it has been reported as found in the scheelite, close search by J. C. Walton, the consulting engineer at the mine, and by the writer failed to show such occurrences. Most of the country rock surrounding the Sidney vein is a graphitic schist which contains thin quartz veins between its laminæ. Many assays have been made upon this quartz, but no gold has been found in it. Here and there, however, it contains a small amount of scheelite. It is probable that the scheelite found in the Sidney veins is related more to the veins intercalated with the schist than to the gold-bearing veins, and that the scheelite has been introduced into the latter at points where they had been fractured. The veins which carry the larger amounts of scheelite, such as those occurring on the Winnie and on the Jersey Lily (north of the Blackhawk), have a considerable amount of a green mineral, probably chlorite, in silicified walls, which shows at least that they were deposited by a different ore-bearing solution.

In the Corona claim, 3 miles south of Randsburg, on the 50-foot level, a lens of quartz 5 inches thick contained about an inch of albite feldspar in the midlde. A sample taken from this part of the vein was crushed and panned and gave a good prospect of gold in small "colors," probably equivalent to more than $25 a ton.

The veins in the Stringer district are all more or less disturbed by faults. On the Bully Boy, 2 miles south of Randsburg and three-fourths of a mile west of the Sunshine mine, a vein which was rich at and near the top is cut off 75 feet below the surface and has not been found again. On the Corona, Sunshine Fraction, and Sidney claims the veins are also badly faulted, but the Sidney vein is more continuous than the other two.

The Gold Coin and Stanford claims, three-fourths of a mile east of the Sunshine mine and nearly 2 miles southeast of Randsburg, have a combination of both fissure veins and fault lodes. Along the fault in silicified crushed material there are lenses of rich ore carrying visible gold. Besides the fault lode there are a number of narrow veins, some of which are little wider than a knife blade, but in places they reach a thickness of 8 inches. The veins in some parts carry over $120 a ton in gold. The richest parts are said to be where there is most iron oxide. The oxide is probably derived from the oxidation of arsenopyrite and pyrite.

The main fault runs east-west and dips about 25° N., but with variations. Little ore has been taken out below the 100-foot level (measured along the dip), and below that the crushing is less and oxidation is much less, pyrite and arsenopyrite appearing.

The veins in general strike with the course of the fault, but locally they branch and converge and dip in all possible directions.

VEINS OUTSIDE OF THE STRINGER DISTRICT.

Outside of the Stringer district veins on the St. Elmo claim, 5½ miles southeast of Randsburg, should also be classed as fissure veins. The veins cut granite and the two principal ones strike N. 30° E. and N. 40° E. The former dips 78° N. 60° W. and is 4 to 10 inches thick. The other is practically vertical and reaches 2 feet in thickness. It is reported that $45,000 was taken from a small open cut between 10 and 15 feet deep on the vertical vein. Several shafts were sunk in search of other ore bodies, and some stoping was done on the veins, but apparently no large bodies of ore were found, as the mine has not been operated for three years or more. The ore is quartz carrying visible gold and is said to have been very rich. Scheelite is said to have been found in pannings of the crushed ore, but none was found in a specimen tested by the writer.

The mine is situated in comparatively level ground and no other paying gold ore has been taken out nearer than the Blackhawk mine, about 3 miles northwest, though there is a narrow, short gold-bearing vein a mile north by west on the Murphy claim, in the Atolia scheelite belt. The vein is practically parallel to the scheelite veins. It strikes east-west and is vertical. A shaft 20 feet deep has been dug on it and enough gold was taken out to pay for the labor.

SUMMARY AND THEORY OF ORIGIN OF THE GOLD.

The rocks of the Randsburg quadrangle may be summed up as follows: Granites of different textures and compositions, covering about five-tenths of the quadrangle, occur in the south and north; mica-albite and chlorite-albite schists, of unknown age and believed to be of sedimentary origin, with some interbedded quartzite and limestone, occupy over one-tenth of the area and form the Rand Mountains; somewhat metamorphosed sediments, probably of Paleozoic age, in cluding many beds of limestone, occupy less than one-tenth of the quadrangle; lavas, probably of Tertiary age, composed of rhyolite, andesites, basalts, and others, occupy more than two-tenths of the area; sand and other unconsolidated fragmental coverings hide somewhat less than one-tenth of the rocks of the quadrangle.

A large crescent-shaped granitic intrusion, 4 miles long and one-half mile wide, cuts the schists of the Rand Mountains on the south side of Randsburg. Near this, and probably connected with it, are many porphyry dikes of widely varying composition.

The rocks are extensively faulted, and the faults near the Rand Mountains are believed to have been largely caused by stresses accompanying the intrusion of the granite. Some granite porphyry dikes were intruded along the faults, after the fault lines were established, as there is much crushed material alongside the dikes. There has been some movement in the faults since the intrusion of the dikes, and they have been more or less shattered by it. In other places the strike of the porphyries is across that of the faults, but nowhere are they known to cross the faults without displacement. Most of the faults and fractures due to the intrusion of the granite strike within the northwest and southeast quadrants.

The principal gold deposits lie in the schist area, rather closely connected with the granite. They may be divided into three principal groups:

1. Fault lodes, deposits along faults in crushed schist and granite.
2. Stockworks in granite.
3. Fissure veins, with more or less quartz.

All three types occur in the Yellow Aster mine.

The mines north and east of Randsburg are of the fault-lode type.

Although stockworks form some of the most important deposits in the Yellow Aster mine, no other mine has produced much ore from them.

In the Stringer district, lying south and southwest of Randsburg, the working mines are all upon narrow fissure veins which have a maximum width of 2 feet and a maximum length of 500 feet. All are badly cut by faults.

The ores in the fault lodes and stockworks are greatly oxidized where productive, and all shafts are comparatively shallow.

It seems probable that after the intrusion of the granite and the granite porphyry dikes a large amount of hot water was squeezed from the granite while it was cooling. The water carried silica, gold, silver, iron, sulphur, arsenic, lime, tungsten, and a little tellurium and titanium in solution and flowed along the faults and shearing planes and through the broken granite. The minerals were deposited wherever chemical reactions or cooling took place. The quantity of silica in the water was evidently not large. It seems possible that the constitution of the watery solutions changed from time to time, as along some veins there is much more alteration of the wall than along others close by in the same rocks. The veins with the more altered walls carry scheelite with very little gold, whereas the gold veins have less altered walls and carry little scheelite.

THE WEAVERVILLE-TRINITY CENTER GOLD GRAVELS, TRINITY COUNTY, CALIFORNIA.

By DONALD FRANCIS MACDONALD.

INTRODUCTION.

Placer mining has been carried on along upper Trinity River and its tributaries since the early fifties. Of late years, with the exhaustion of the small rich diggings, the sluice box and rocker have given place to the hydraulic plant and the dredge, and these have now opened up great bodies of low-grade gravel. This short report is the result of observations incidentally made while examining placer claims near Minersville, Trinity National Forest, in July and August, 1909. Acknowledgments are due to nearly all the mining men in the district for interest, information, and ready courtesy, but especially to Mr. Bouery, of the La Grange mine, and Mr. MacIlwaine, of the Dorleska. Frequent reference has been made to the interesting articles of O. H. Hershey on the geology of this general region and of D. F. Campbell[a] on the La Grange mine.

LOCATION AND PHYSIOGRAPHY.

GENERAL DESCRIPTION.

Trinity River flows west of south through the northeast part of Trinity County to Douglas City (fig. 2), and from there on until it joins the Klamath its course is northwest. West of the present Trinity Valley and as a southern spur of the main Siskiyou Range, the Sierra Costa[b] rises above the dissected remnants of a peneplain that stand at an elevation of about 4,000 feet. To the east this peneplaned surface is shown in Trinity Ridge and other low level-topped ridges which slope gently southward from the main Siskiyous. Rejuvenation intrenched the drainage in this old peneplain and Trinity River and its tributaries established a new base-level at an elevation of approximately 3,000 feet. This is shown by

[a] Campbell, D. F., Min. and Sci. Press, October 10, 1908.

[b] Described by O. H. Hershey in Am. Geologist, vol. 25, p. 76.

the accordance in summit level of the divides between East Fork and Trinity River and between the following creeks: Rush and Buckeye, Rush and Browns, Oregon Gulch and Weaver. Along the wagon road over the Rush Creek divide washed gravel was observed. This second cycle of erosion was important economically, for it left most of the auriferous gravels of the district which are now being mined. Since the beginning of the third cycle the drainage has been lowered several hundred feet and the bottoms of these new valleys have been considerably widened. This cycle also caused a concentration

FIGURE 2.—Sketch map of northern part of Trinity County, Cal.

of values in the gravels, especially those near the level of the present Trinity River.

GLACIATION.

Near the beginning of the second cycle of erosion glaciers moved out a few miles from the mountains north and west of Minersville and Trinity Center. They left the western edge of the old peneplain covered with a hundred feet of drift from the complex igneous and metamorphic masses that constitute those mountains. At least two distinct periods of glaciation were recognized. The first deposited the highly oxidized material typically shown on the flat-topped ridges northwest of Minersville; the effects of the second, comparatively recent, are best seen on the headwaters of Coffee Creek and Salmon River. Hershey [a] has called attention to the glaciation of the district and to the capture of upper Coffee Creek by Salmon River, a change in drainage greatly facilitated by the recessional morainal material left in the old Coffee Creek valley 5 miles below its head. This obstruction caused a lake, which soon overflowed into the headward-working Salmon. The upper Salmon now follows the glaciated valley, formerly Coffee Creek valley, to the morainal obstruction and then turns to the left through a V-shaped canyon. The present Coffee Creek rises in this glacial débris and occupies its old U-shaped valley below the drift barrier.

The fresh and unaltered appearance of the till here, and especially of the perched bowlders, is in striking contrast to the highly weathered condition of the older drift on the flat-topped remnants of the 4,000-foot peneplain northwest of Minersville. The upper 6 feet of the latter is weathered into reddish soil. This, together with a growth of brush and timber, masks its glacial character, except where deeply eroded by streams and ditches. Moreover, since deposition Mule and Strope creeks have cut through it and 100 feet into the underlying bed rock. Altogether this material appears to be at least ten times as old as the fresh drift and perched bowlders of upper Coffee Creek. Between these two extremes other periods of glaciation may have occurred.

Around the periphery of a large and irregular granitic batholith, in the mountains from which the ice came, are several gold veins, some of which have been fairly productive. It is believed that the glaciers removed at least the upper portions of veins such as these and left fragments of them in the glacial débris. This is shown by the angular pieces of quartz and sharp-cornered "colors" that occur locally in the drift, especially in the weathered upper portion. This formation was called "dead wash" by the early miners because they found it practically barren. From this glacial till, however, the present auriferous gravels were mostly concentrated. Weathering first disintegrated the bowlders, giving a residual product of clay and gravel and any contained "colors" of gold; stream action then re-sorted this, leaving the auriferous gravels that are mined to-day. Glaciation here, then, has had a direct economic value, for it ground off the mineral veins and carried their fragments to the valley, where weathering and stream action could more rapidly carry on the concentration.

[a] Jour. Geology, vol. 8, No. 1, p. 46, and Am. Geologist, vol. 31, March, 1903.

PLACER MINING.

In the early fifties prospectors first visited this region, and soon from many gulches came the sound of whipsaw and pick. Busy little camps sprang up and mule trains pioneered their way across the forested mountains, bringing supplies. To-day the old camps are gone, but centrally situated little towns have taken their place. Wagon roads have supplanted the pack trails, and the old sluice box and rocker have largely gone to decay because of the successful exploitation of great bodies of low-grade gravel, which gives brighter promise for the future. The annual yield of placer gold in Trinity County during the last few years has ranged from $350,000 to $500,000, according to statistics published by the United States Geological Survey.

LA GRANGE HYDRAULIC MINE.

LOCATION.

The La Grange mine is at the head of Oregon Gulch, 5 miles west of Weaverville and 56 miles northwest of Redding, the nearest railway

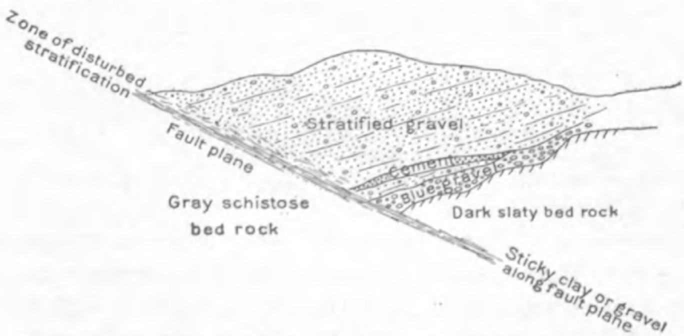

FIGURE 3.—Section across the La Grange channel, west of Weaverville, Cal. The part marked "Stratified gravel" is the tilted gravel bed 600 feet deep and a mile wide, showing a lens of cement gravel near its base.

station. It is owned by the La Grange Hydraulic Gold Mining Company, composed principally of eastern capitalists, and is managed by Pierre Bouery. In equipment and amount of material handled the mine is perhaps second to none in the world.

GEOLOGIC RELATIONS.

The deposit is on an old channel—La Grange Channel—formed by Stewarts Fork or by Trinity River. If it was formed by Stewarts Fork that stream then joined the main Trinity near or below the mouth of Oregon Gulch. The deposit represents a phase of the period when the 3,000-foot base-level was being established and seems to show two mutually unconformable but fairly well stratified gravels. Subsequent faulting and shearing have locally disturbed the stratification and tilted the whole to the southwest, as shown in figure 3. From rim to rim the width of this channel is almost a mile and its greatest depth is 600 feet. Its direction here is determined by its northern rim, which is a great smooth, slickensided fault plane trending N. 70° E. and dipping 22° S., and the striæ on which make a small angle with the horizontal. Along this fault a parting of sticky clay, a few feet thick, separates the gray schistose rock on the north from the dark, slaty, rough-surfaced bed rock on the south side. The stratification of the gravel along this plane is much disturbed, indicating that the throw of the fault must have been considerable. The wash is fairly fresh and contains a great variety of rock; about 12 per cent of it consists of bowlders weighing from 100 pounds to many tons. Near the lower part of this bed is a lens-shaped layer of cement gravel, having a maximum thickness of 50 feet. Below this indurated bed uncemented stratified wash forms the basal part of the younger gravel and rests with apparent unconformity on an older blue gravel.

The so-called blue gravel rests on an uneven surface of slaty bed rock. It presents a much more squeezed and sheared appearance than the upper gravel and shows many stones and bowlders flattened and fractured. Though not a cement gravel it has a much more resistant matrix than the overlying material and shows more small faults, the the principal of which trend N. 40° E. and dip 65° SE. The coloring matter which has given the name to the gravel is probably iron reduced to ferrous compounds by an excess of organic matter.

WATER SUPPLY.

A maximum flow of 3,400 miner's inches of water is conveyed to this mine from Stewarts Fork, 29 miles distant. The headworks consist of a dam giving at present a storage capacity of 13,000 miner's inches, which will next year be increased to 90,000. From this reservoir 8½ miles of flume brings the water to the first inverted siphon, which has a span of 4,800 feet with an 1,100-foot depression and is built of 30-inch steel pipe with lower lengths one-half inch thick. Beyond this siphon there is a 9,000-foot tunnel, two inverted siphons, one with 150 feet difference between head and discharge, the other with 60, and a flume and ditch leading to the reservoirs at the penstock. The flume, 2 feet wide in the bottom, 6 feet wide on top, and 4 feet deep, is built of 4 by 6 inch framework lined with 1½-inch boards. The flume cost $5,000 to $7,000 a mile, the tunnel $10 a running foot.

From the penstocks three main pipe lines carry the water to six giants working under 450 to 650 feet of head, and three of these, together with a smaller one, work at once. The largest pipe is 30 inches, the smallest 15 inches; the gage is No. 4 to No. 7. The mains have 15 to 18 inch inlets and 5 to 9 inch nozzles and are fitted with safety clutches, invented by Mr. Bouery, to prevent accident in case the kingbolt should snap and the top of the giant break loose. These immense giants are fitted with a modified form of "bootleg" deflector and with saddles, so that the piper rides the swinging pipe and has it under perfect control at all times with a minimum amount of exertion and a maximum of safety and efficiency. The reservoir gates are fitted with automatic floaters for regulating the discharge so that the same amount of water a minute will flow whether the reservoir is full and the pressure great or the reservoir nearly empty and the pressure correspondingly low.

MINING AND EQUIPMENT.

In mining, the 600-foot bank is undercut along the bottom and slowly crushes down, breaking even the lens of cement gravel near the base. This undercutting saves the large blasts formerly necessary, and now only the larger bowlders and masses of cement gravel which do not crush small enough are blasted. These are drilled by hammer drills, run by a small water-driven air-compressing plant. This method is much more efficient than "bulldozing" or lifting out with a water-power derrick, as was formerly done. Large masses of clay are encountered along the main fault plane; these are bored with an Ingersoll wood-boring machine, using a seven-eighths inch bit, and blasted. The high-pressure pipes accomplish the cleaning of the bed rock, so that scraping is unnecessary.

The sluice boxes are 4 by 6 feet in cross section and are set into bed-rock cuts blasted out with the aid of water liner No. 6 drills. They have a uniform grade of 8 inches per 12 feet for all except the first 70 boxes, which are set at 7 inches. The sluice is lined with 40-pound steel rails throughout its 3,000 feet of length. The bottom rails are all set crosswise except a few lengths near the upper end laid lengthwise to help give the material a start. Rails set lengthwise and 8 inches apart last two months; lengthwise and 5 inches apart, four months; crosswise and 5 inches apart, six months. The interval of 5 inches has been adopted for the bottom rails; these are held in place and spaced by cast-iron lugs bolted to one rail and having a square depression in the other end, which fits on the head of the bolt holding the lug to the next rail. The rails may thus be readily removed at clean-up time without unscrewing any bolts. They are set on 2 by 6 inch pieces spaced by 4 by 6 wooden end and center blocks, thus forming 10-inch riffles. When the top part is worn off the rails are heated in a special furnace, straightened, and used to line the sides of the boxes. For this lining they are set with the web or stem of the T between thick plank strips and with the flat basal part projecting out over the strips, thus armoring the sides of the sluice. Long bolts passing downward through the strips and rail stems hold them in place. The rails are shipped from San Francisco already drilled and cut into 6-foot lengths. Each length, with lugs attached, costs at the mine, after paying $1.25 for drayage from Redding, about $5. Each of the 140 or more sluice boxes contains 30 transverse rails. About 1,400 feet from the head of the sluice the material can be diverted by means of a steel door to another part of the dumping ground. This exit gives more dump area and facilitates the clean-up of the lower sluice. Through this great iron-clad sluiceway material is washed at the rate of 1,000 cubic yards an hour, even bowlders up to 7 tons in weight being carried through.

Formerly the sluice was lined with wooden blocks 16 by 16 by 13 inches. These wore out so rapidly that a clean-up and relining were necessary every two to three weeks, causing great loss of time and expense. Sanding up, too, often gave trouble, and it was difficult to save the fine gold if the sluice was allowed to carry anywhere near its full capacity. With the present equipment the sluice can be run full day and night, and only three clean-ups a year of the first 40 or 50 boxes are necessary. The lower boxes are cleaned less often. Below the forks of the sluice a clean-up is made about once in two years, and is carried on without interruption of mining by using the other branch of the flume. From a diagram worked out by Mr. Bouery, which shows the curves of settlement of the various sizes of gold in the sluice boxes, the following facts are taken: The largest percentage of the gold recovered is too coarse to go through a 10-mesh screen. The maximum recovery of this size is in the eleventh box, but boxes 5, 12, and 13 have each almost as much. From this point the decline is very rapid to box 22, less rapid to box 48, and thence tails out toward the end. The next size, between 11 and 50 mesh, is less plentiful and reaches a maximum in box 12. From there it declines very rapidly to box 22, then less rapidly to box 48, and gradually to box 136 or beyond. All smaller sizes are much less plentiful than the coarser product. Sizes between 50 and 100 mesh are recovered in quantity in the first boxes, but reach a maximum in box 22. Sizes 101 to 150 mesh are most abundant in box 6, and sizes 150 to 200 in box 13. In spite of the vast amount of material handled and the absence of an undercurrent, gold which will go through a 200-mesh screen is caught in the first box and reaches a maximum somewhere near the twelfth box. Mr. Bouery, in the presence of the writer, poured some of this fine gold, which had been dried, into a glass of water, and much of it floated on the surface film. This great efficiency in catching the values is accounted for by the little whirl of water that forms behind each rail riffle, owing largely to the concavity along the web of the rail between its top and basal projections; also by the absence of sanding and by the pounding action and cross currents from the bowlders as they are carried along. The high efficiency in the saving of gold, the splendid water supply and great depth of gravel, the natural V shape of the bed-rock channel, the dumping facilities, and the efficiency of equipment and management are some of the advantages that result in the low mining cost of this ground, which is estimated at less than 2 cents per cubic yard.

In the sluiceway 1 pint of quicksilver is sprinkled in boxes 1 to 30 every thirty-six hours, 1 quart every two weeks in boxes 31 to 100, and 1 quart every two months in the boxes from 100 to the end of the flume. Most of this is recovered by retorting; the amount actually lost, largely from flouring, is only about 112 pounds per year. The retorts are lined with chalk to prevent adhesion of the gold, and the mercury recovered is refined by heating it with charcoal and some cinnabar. A gasoline furnace and graphite crucibles are used for melting the amalgam, and the slag from it is poured off and run into base bars valued at a few cents an ounce.

The office, boarding house, mine, and ditch line are all connected by telephone, and every ditch tender's cabin is fitted with an electric call bell attached to a float in the flume, so that if the water rises or lowers quickly the alarm is sounded. There is a sawmill at the head of the ditch, and the lumber is floated down to the siphons, where it is shot down the slope of the gulch, trammed up the other side, and again flumed to the place where it is required. An electric-light plant, an electric-heated chamber for thawing powder, a small ice-manufacturing plant, a blacksmith, machine, and pipe shop, and a heating furnace for straightening rails, all run by water power, make the equipment of this mine very complete. The saving of labor by these various devices makes the general running expenses low. Only about 30 men are employed in the mine altogether; 10 of these patrol the ditches, leaving 20, including blacksmiths, machinists, and office force, available for two shifts. The mine men are paid $3 a day of ten hours. The pipers and their helpers work twelve-hour shifts.

HISTORY AND FUTURE PROSPECTS.

Oregon Gulch was first mined in the fifties. In 1872 the Trinity Gold Mining Company installed a small hydraulic plant, which was worked until the La Grange Company took over the property in 1892. This company brought water from Rush Creek with a 14-mile ditch, instead of using the 7-mile system which furnished, for three months each year, 1,500 miner's inches of West Weaver Creek water to the old workings. In 1896 the Rush Creek ditch was extended 14 miles to Stewarts Fork, and soon afterward the present splendid water system was put into use. The annual mining capacity for the first few years after the present company took hold was about 2,000,000 cubic yards. This capacity has gradually been raised until now about 5,000,000 cubic yards of material is sluiced out each year.

No statement of the total production to date is available, but it is estimated to run into the millions of dollars, and the work may be said now to be only well under way. In addition to the enormous quantity of gravel (100,000,000 cubic yards, according to Mr. Bouery) available before the crest of the Oregon Gulch-Weaver Creek divide will be reached by present mining operations, there is some topographic evidence that this same channel passes just north of Weaverville and north of Browns Mountain across to the headwaters of Buckeye Creek. No time was available to trace out the trend of this old channel, but the topographic configuration is suggestive enough to warrant prospecting in this vicinity. Of course these water-laid, low-grade gravels should be carefully distinguished from the barren glacial débris locally known as "dead wash," which is typically shown on the flat-topped ridges at about the 4,000-foot level northwest of Minersville and which may also be expected to occur on the higher ground a considerable distance northwest of Weaverville. It is probable that several decades of mining will be required to exhaust the gravels of the La Grange channel.

OTHER PLACERS NEAR WEAVERVILLE.

Large deposits of placer gravel occur near the town of Weaverville. Of these the most important is owned and has long been operated by Hupp Brothers. These gravels are probably very little younger than the deposits of the La Grange channel, but the concentration seems to have been carried somewhat farther. Rocker and sluice were used for many years on the creeks near Weaverville, and there now seems to be but little gravel left that it would pay to work by hand.

MINERSVILLE AND TRINITY CENTER PLACERS.

At Minersville the principal hydraulic mine is owned and operated by the Trinity Gold and Milling Company, of which Mr. Whipple is general manager. Their gravel deposit is from 100 to 200 feet above East Fork of Stewarts Fork and several hundred feet below the "dead wash." It occurs at an elevation of about 2,500 feet and may be younger than the gravels of the La Grange channel, although such a correlation is not wholly to be relied on because of the faulting of the latter. As no high rim was noticed clearly separating this deposit from the present stream, it is thought to be a bench deposit rather than a true "old channel." Though not of high grade, it is large and will furnish material for many years of mining. This deposit should be carefully differentiated from the "dead wash" which covers the ridge tops a few hundred feet higher up and just northwest of it. The latter is a barren glacial till, entirely distinct, geologically, from any of the gold-bearing gravels of the district.

A few miles farther up East Fork of Stewarts Fork are large and promising benches of gravel, which would probably yield returns if worked with a sufficient head of water. Some of these, especially the property formerly owned by J. C. Van Matre, are said to have paid while worked with a low pressure of water. These properties were idle at the time of visit, owing, it was said, to lack of sufficient capital to replace with a larger system the old flumes which two years earlier had been destroyed by washouts.

At Trinity Center the chief hydraulic property now producing is that owned by the Sykes Gulch Mining Company. Here 150 feet of gravel covered by 50 feet of reddish clay overlies a shale bed rock. Water amounting to 1,300 miner's inches is brought 7 miles by ditch and under 285 feet of head supplies a giant having a 7-inch nozzle. Active mining begins October 1 and continues until the water supply gives out about the middle of July. The gold is smooth and worn and fairly coarse. The values are rather evenly distributed through the gravel, but there is slight concentration as bed rock is approached. The flume is lined with square blocks 10 inches thick and five sets of these are used each season. The bed rock is soft and is cleaned by piping. The estimated cost of mining is about 3 cents per cubic yard. Much mining has been done here, and the gravel seems to be of about the same age as that at Minersville. The deposit is from 200 to perhaps 600 feet above Trinity River.

COFFEE CREEK PLACERS.

Two other active placer mines of importance are the Nash, on West Coffee Creek, near the mouth of Union Creek, and the Holland placer, on East Fork of Coffee Creek. Both are approximately 16 miles north of Trinity Center. Both are worked by sluicing out the creek bottom with large automatic reservoirs, the rim material usually being piped into the main ground sluice. The clean-up consists of diverting the stream from its channel in the sluiced-off area and shoveling the concentrates from the bed rock of the ground sluice into sluice boxes. This method of mining requires that the stream shall have considerable grade, that the bed rock be not too deep, and that the gravel be uncemented and have comparatively few large bowlders. As these two properties are similar and are worked by the same method, but one will be described.

The Nash mine is operated with a reservoir having a capacity of 300,000 miner's inches, built on the creek some distance above the ground now being mined. A 12 by 12 foot gate opens automatically when the reservoir is full, thus sending a vast flood of water down the ground sluice in the stream bed. A ditch 5 miles long supplies 1,000 miner's inches of water under 218 feet head to a giant with a 6-inch nozzle, which is used to pipe the rim material into the ground sluice. The average width of the channel is 40 feet; depth along central axis, 20 feet; grade, 2½ inches per 12 feet; cost of working, about $600 per 100 feet of channel. A flume at the lower end of the bed-rock ground sluice, to catch fine gold, is 72 feet long, 16 feet tapering to 12 feet wide, and 6½ feet deep. Along the bottom it is laid with 18 by 18 by 12 inch blocks, which wear three-fourths of an inch each season of six or seven months' active sluicing. This property is said to have produced about $150,000 since its first development in the early eighties.

FUTURE PROSPECT FOR PLACER MINING IN THE DISTRICT.

There are large deposits of low-grade gravels in the district which are yet untouched, and some of these are workable, though perhaps at considerable expense, by hydraulic methods. Here no antidébris laws hinder the miner, the mountain streams furnish a fair supply of water, timber is abundant, and dumping facilities are in general better than in most hydraulic mining regions.

Along Trinity River are many high bars and low benches which give pan prospects sufficient to invite investigation with a view to dredging. A dredge has been operated near Trinity Center for some time, and it is reported that the extensive diamond-drill prospecting recently carried on there will soon result in the installation of others. The upper Trinity River district is a field which is worthy of examination by dredger men as well as by those interested in hydraulic mining.

PLACER GRAVELS OF THE SUMPTER AND GRANITE DISTRICTS, EASTERN OREGON.

By J. T. PARDEE.

INTRODUCTION.

During the summer of 1909 some information was obtained concerning placer mines in an area approximately consisting of the following drainage basins: In Baker County, North Powder River above Red Mountain, Rock Creek, Pine Creek, Goodrich Creek, and Powder River above Sumpter; in Grant County, North Fork of John Day River above Lake Creek, Onion Creek, Crane Creek above Crane Flats, Granite Creek, and Clear Creek.

Placer mining has been carried on in this area since 1863. Practically all the gravels that could be easily attacked have been mined out. Certain deposits, however, that were less favorably situated as regards water supply or dumping facilities remain. The object of this paper is to describe these deposits and briefly discuss the relation of the gravels to the glaciation of the region.

The thanks of the writer are due Mr. F. C. Calkins, of the Survey, for valuable criticism and advice.

The placer gravels of this area (fig. 4) may be separated into two groups. They are, in order of age:

1. High-terrace or intervolcanic [a] gravels. They are highest in relative position and probably of Miocene age.

2. Gulch or valley gravels and some low-terrace gravels closely associated with them. This group occupies the lower relative position and is mainly of Pleistocene age.

HIGH-TERRACE GRAVELS.

GENERAL DESCRIPTION.

The high-terrace gravels are the remnants of the alluvium deposited in the valleys of an ancient river system that was probably the ancestor of the existing one. Although the relations of the two have not yet

[a] Lindgren, W., The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 636.

been entirely worked out, enough is known to indicate that these ancient streams were interrupted and their valleys filled in places by volcanic material, and that the streams thus forced to seek new channels have subsequently cut down a few hundred feet beneath their former levels, leaving such portions of the ancient gravels as were not removed in the process "high and dry."

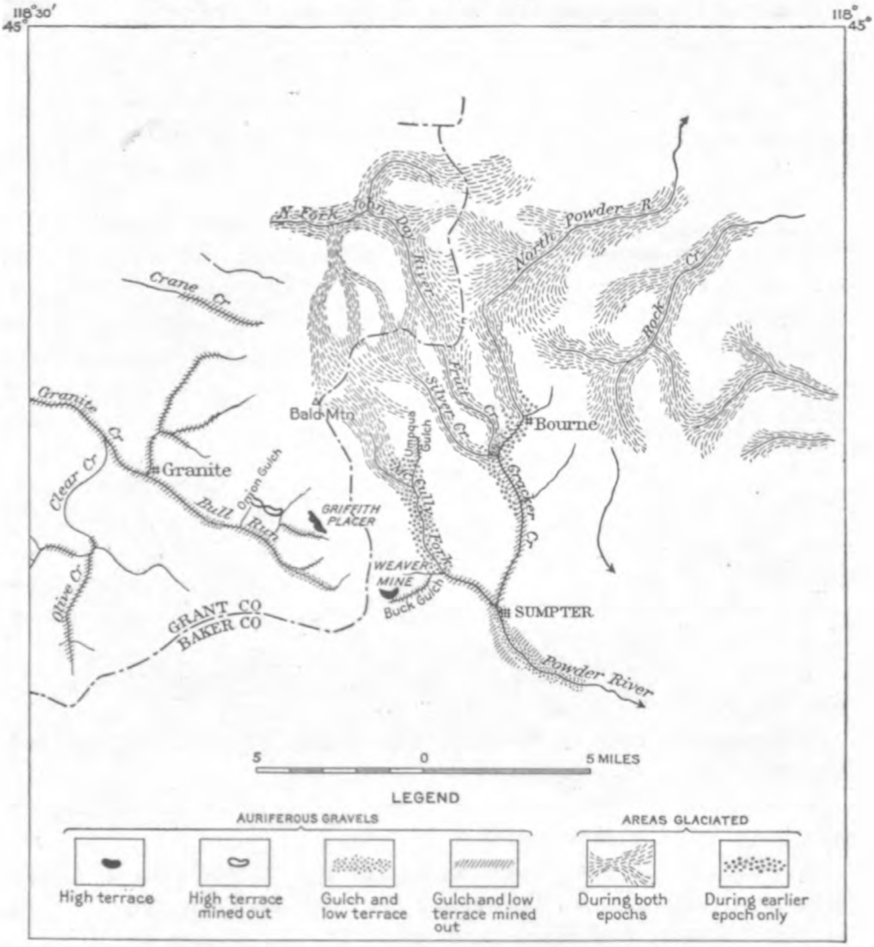

FIGURE 4.—Map of a portion of the Sumpter quadrangle, Oregon, showing distribution of gold-bearing gravels with relation to glaciated areas.

WEAVER MINE.

The Weaver mine is situated near the head of the north prong of Buck Gulch, in a gravel terrace hanging upon the north slope some 200 feet above the bed of the ravine. Its elevation above sea is 5,550 feet. It extends as an ill-defined bench, having a course approximately east and west, 1,000 feet or more, its western termination not being exposed. In its eastern portion pits 50 to 90 feet wide and aggregating 450 feet in length have been made, exposing a bank 40 feet high. These openings have apparently reached not more than halfway across the deposit. In part the gravel rests unconformably upon loosely consolidated fine sands and silt, which in turn rest upon a bed rock of cherty shale and basic igneous intrusive rocks. The gravel consists of smooth rounded cobbles of an average diameter less than 12 inches, in an abundant sandy matrix that is very loosely "cemented." It is thickly bedded, striking N. 75° W. and dipping 6° to 8° N., and together with the bed rock is affected by several normal faults of small throw; one of these, striking N. 70° E. with vertical dip for a short distance, forms the outer boundary of the gravel, which has dropped, relatively, on the north.

Gold is distributed throughout the gravel but is found in greater quantity in the lower layers. It occurs mainly as small half-rounded grains of pin-head size and dust, with occasionally a small nugget. Its fineness is reported as 900 to 940.

It is stated that here the richest gravel lies on the outer rim.[a] This condition the writer has noted as true of many similar gravels elsewhere, and so far true in some instances that only the outer rim was rich enough to pay. The difference is probably due to a secondary concentration during the slow removal of the exposed edge of the gravel by erosion.

The Weaver property is equipped with a small hydraulic plant and supplied with water through a ditch about 6 miles long that diverts the flow of Grays Gulch, a tributary of McCullys Fork. Water in sufficient amount for mining purposes is had only during part of the spring and summer.

This mine has been operated profitably during the past nine years, but a statement of its output and the average yield of the gravel is not available for publication. The sluices here yield a considerable amount of "black sand," a sample of which was examined in the Survey laboratory. A few specks of platinum were detected in it by D. T. Day. It contained in addition a globule of gold amalgam and a few small flattened particles or "colors" of rusty gold.

South and southeast of the Weaver mine, on the opposite slope of Buck Gulch, and on the divide between it and Mosquito Gulch, fragmentary patches of gravels are poorly exposed at elevations of 5,500 to 5,600 feet. They greatly resemble the gravel of the Weaver mine and are thought to belong to the same stream system. On the divide mentioned they are apparently overlain by andesitic tuff.

[a] "Outer rim" among placer miners denotes the rim or bank of an elevated rock channel that lies nearest to or is intersected by the present slope.

GRIFFITH MINE.

The Griffith placers are in a high terrace about 3½ miles northwest of the Weaver mine, at an elevation of approximately 5,500 feet, and on the opposite or west slope of the Blue Mountain divide. The portion of the ridge separating the two places is from 200 to 400 feet higher.

Lindgren[a] has described this deposit and records that in 1900 "a hydraulic pit about 1 acre in extent has been made in the high gravels, and a bank 40 feet high is exposed." The present area of this pit is about the same. Evidently little or no mining has been done since that time. Early in the past season (1909) operations at a point just west of this old pit were commenced, but after a short time they were suspended because of litigation. The gravel here lies unconformably upon fine sediments very similar to those of the Weaver mine and is thickly bedded, striking northwest and dipping 12° NE.

In its general texture this gravel resembles that of the Weaver mine, and it is likewise affected by normal faults, one of which strikes north, with vertical dip and downthrow of 6 feet on the west.

Considerable "black sand" is said to collect in the sluices, and a sample of it was obtained from G. V. Pinson. Platinum was detected in this sample by D. T. Day, in greater quantity than in the sand from the Weaver mine, amounting to about 1½ ounces per ton. (The present market value of refined platinum is $29 per ounce.) In addition, this sample contained a considerable amount of gold amalgam and a few flat particles or "colors" of rusty gold. Both this and the sand from the Weaver mine are by the partial examinations made shown to be well worth saving. These occurrences of platinum are interesting as being from new localities, and the metal's close association there with serpentinized rocks is in line with its general occurrence elsewhere.

The extent of this deposit has not yet been definitely determined by prospecting. It seems, as noted by Lindgren,[a] to extend northwestward for a mile or more, and apparently disappears under a basalt flow.

ONION GULCH.

A considerable deposit of the high-terrace type, lying in a basin at the head of Onion Gulch, has been mined and abandoned. It is about 3 miles northwest of the Griffith mine, at an elevation of 5,100 to 5,200 feet, and is of interest now mainly in its relationship to the deposit at that mine. From a general similarity in the character of the gravels and the elevations and courses of their channels it appears possible that they are remnants of the same deposit. Deep

[a] Op. cit., p. 688.

Creek, whose course is transverse to this ancient channel and whose stream bed at the crossing is now some 300 feet lower, affords a measure of the canyon cutting since that time.

The gold of this group was no doubt derived from the bed rock within the drainage basins of these ancient streams, but apparently not from the immediate vicinity of the existing gravel remnants.

LOW-TERRACE AND GULCH GRAVELS.

Included in low-terrace and gulch gravels are the bench gravels or "bars" found along either side of the present streams, usually lying 20 to 50 feet above them. They record a temporary halt in the Pleistocene downcutting of the streams, the specific cause for which has not yet been determined. The subsequent excavation of the valleys to the present level has left remnants of these deposits. They are found mainly along McCully Fork above Sumpter and along Granite Creek below Granite and Lawton. Their gold content appears to have been derived not alone from the erosion of the bed rock but largely from the high-terrace gravels. When Lindgren saw these deposits in 1900 some mining was still in progress.[a] Since then they have been practically worked out and abandoned. Near Sumpter, on the benches bordering Cracker Creek and McCully Fork, there still remain some patches of gravel aggregating 2 or 3 acres; and the lower layers of gravel in the southern portion of the Ellis mine have been left, apparently because they were situated too low for sluicing.

Somewhat younger, but closely related in history to the low-terrace deposits, are the accumulations along the beds of the present streams. They were the first to be exploited and have been mined to exhaustion where value sufficient for ordinary mining methods is found. The gold of these deposits was derived not only from the bed rock but in some instances at least in greater part from the high-terrace gravels. This is notably true of Buck Gulch and the upper course of Bull Run.

The low-terrace and gulch gravels may be classed according to richness into three minor groups, which are given below with the streams in which each is found:

1. Comparatively rich gravels, in Buck Gulch, Bull Run, Granite Creek, Crane Creek, Olive Creek, and Umpqua Gulch. So far as evidence can be obtained the gravels of these streams have produced the greater part of the gold credited to the area under consideration.

2. Comparatively lean gravels, in Cracker Creek, from Bourne to Sumpter, and McCully Fork, from Sumpter upstream 3 or 4 miles.

3. Practically barren gravels, in Fruit Creek, Silver Creek, Rock Creek, upper course of North Powder River, upper course of North

[a] Op. cit., p. 656.

John Day River, Cracker Creek above Bourne, and upper course of McCully Fork, excepting Umpqua Gulch.

The leanness of the last two groups is apparently not due to the poverty of the bed rock eroded, but is to be explained mainly as a result of glaciation, which has affected all these valleys more or less but has been entirely absent from those containing the rich gravels. The glacial history of this region is briefly as follows:

(*a*) An earlier glacial epoch in which ice extended down Cracker Creek to a point within 2 or 3 miles of Sumpter and down McCully Fork somewhat below the Granite stage-road crossing. All the valleys of the third or barren group were more extensively glaciated. The effect of this invasion upon the gravels, rich and poor, was to mix them, dilute with other débris, and shift the whole mass downstream.

(*b*) An epoch in which the ice disappeared and the streams to a great extent reconcentrated the jumbled mass left by the glacier. The lean gravels of Cracker Creek are a product of this epoch, as are in great part the low-terrace gravels of McCully Fork.

(*c*) A reinvasion of the ice that affected Cracker Creek as far down as Bourne and McCully Fork, within 2 or 3 miles of the glacier's former extension, and again glaciated the valleys of the third group. The effect of this invasion was, within its restricted area, similar to that of the earlier one. The more or less re-sorted stream gravels were again removed and left as unsorted worthless morainal material.

(*d*) Disappearance of this later ice and resumption of stream erosion and reconcentration, continuing to the present time. This is the Recent period of geologic history, which has been relatively so brief that the streams have had time to accomplish little in the way of reconcentrating the moraines and practically no erosion of the bed rock.

The relations of the placer gravels of this area to its glacial history thus impressively bring out the vast length of time required for the concentration of gold by the sluicing action of streams.

EXTENT OF REMAINING GRAVELS.

HIGH-TERRACE GRAVELS.

At the Weaver and Griffith mines a rather indefinitely known but considerable body of the high-terrace gravels remains, which may be expected to produce moderately for several years.

LOW-TERRACE AND GULCH GRAVELS.

In addition to those noted on page 63, the remaining low-terrace and gulch gravels are those of Bull Run and Powder River. Along Bull Run there remains a considerable amount of gravel upon a bed rock of too slight grade to permit the application of ordinary mining methods. The largest area of this description lies a short distance below Gold Center. It is a mile or more in length, of irregular width, averaging perhaps 200 feet, and about 10 to 15 feet deep. A dredge, under the management of Captain Wetherall, is being installed to work this deposit and is expected to be ready for operation in the spring of 1910.

Below the junction of McCully Fork and Cracker Creek, at Sumpter, is a deposit of alluvium in the main stream. It is about 1,000 feet in average width, extends at least 2 miles below Sumpter, and appears to merge with the more extensive alluvium of the main Sumpter Valley.

Prospecting by means of drilling has been in progress on this deposit during the past two seasons, presumably with a view of determining its suitability for dredging. The results so far obtained are not known.

There is a heavy deposit of alluvium, containing large bowlders, in the bed of Clear Creek from Lawton up to the mouth of Lightning Creek and thence up that stream. This gravel, from available evidence, appears to be gold bearing but is of little commercial value at present, owing mainly to the expense incurred in mining such coarse material where the grade is insufficient.

FUTURE PRODUCTION.

A moderate annual output may be expected from the high-terrace gravels for some years to come, and in addition a probable further yield from the dredged deposits.

It is perhaps needless to observe that as a rule placer deposits are not to be expected in a recently glaciated region, and that the absence of placer gold does not necessarily signify that gold quartz is lacking; this fact is illustrated by Cracker Creek, whose tributaries have eroded a great part of the rich "mother lode." On the other hand, the gold of rich alluvium has not necessarily a source within the limits of the particular drainage basin in which it is found; this is illustrated by Buck Gulch, where there is no gold quartz in the bed rock. The disregarding of this principle has in several instances led to considerable expenditures for the development of worthless quartz claims, on the strength of their being situated at the upper limit of rich placer deposits.

SURVEY PUBLICATIONS ON GOLD AND SILVER.

The following list includes the more important publications by the United States Geological Survey, exclusive of those on Alaska, on precious metals and mining districts. Certain mining camps, while principally copper or lead producers, yield also smaller amounts of gold and silver. Publications on such districts are listed in the bibliographies for copper and for lead and zinc. When two metals are of importance in a particular district, references may be duplicated. For names of recent geologic folios in which gold and silver deposits are mapped and described, reference should be made to the table in the "Introduction" to this volume.

These publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the monographs from either the Director or the Superintendent of Documents.

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COPPER.

THE OCCURRENCE OF COPPER IN SHASTA COUNTY, CALIFORNIA.[a]

By L. C. Graton.

INTRODUCTION.

LOCATION.

Shasta County lies just south of the northernmost tier of counties in California, about midway between the eastern and western boundaries of the State. The Shasta County copper region is a somewhat ill-defined area lying near the middle of the western half of the county, 80 to 100 miles east of the Pacific and at about the latitude of New York City. It is included within meridians 122° and 122° 33′ west longitude and parallels 40° 37′ and 40° 50′ north latitude. Next to the Lake Superior district of Michigan it is areally the largest copper region in the United States that can be regarded as a geologic unit. As commonly described, it is a narrow curved belt, convex toward the north, popularly known as the "copper crescent." From tip to tip this bow measures about 25 miles in a direction but little north of east, but the length measured along the curve is nearly 35 miles. In reality this "crescent" or "belt" is simply the locus of a number of deposits or groups of deposits, separated by stretches in which important deposits of copper are not known and throughout most of which such deposits probably do not exist. It is more exact, therefore, to regard the belt, so far as now developed, as a number of detached camps or districts which, more by chance than because of

[a] This paper contains a preliminary statement of the salient features of the Shasta County copper region and of some of the general conclusions already reached, and has been presented, in response to a request by the Geological Survey, in advance of a detailed geologic report now being prepared. It should be borne in mind that although the conclusions herein expressed are for the most part well established by evidence to be presented later, they are not necessarily final and are subject to any modification that may be found necessary as the result of additional study now in progress.

any evident geologic conditions, are situated on a curve. (See fig. 5.) At the west end of this curve are the deposits that extend in a northeasterly direction from Iron Mountain beyond Little Backbone Creek, a distance of about 8 miles; near the middle are the deposits

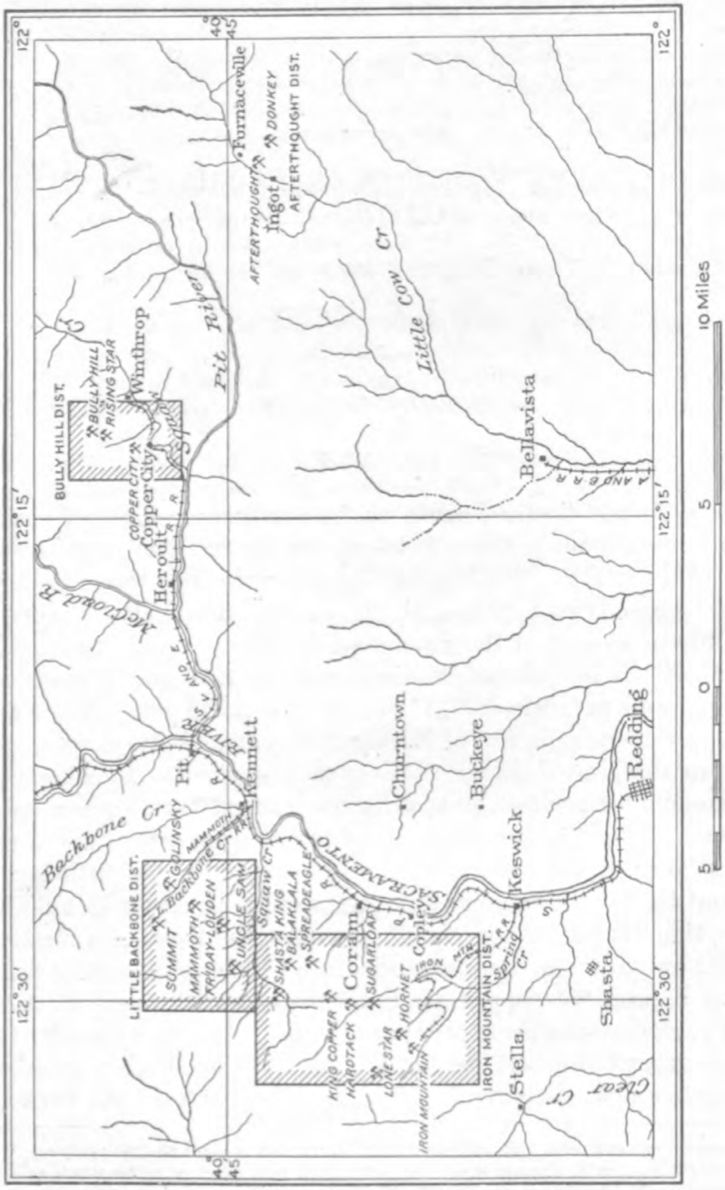

FIGURE 5.—Sketch map of copper region of Shasta County, Cal.

of Bully Hill and Copper City; and on the east are the deposits of the Afterthought district, near Ingot. More or less prospecting has been done at some intervening points.

There is also a common division of the district into two parts, one east of Sacramento River and one west. This division is useful for purposes of geographic description, but although there are certain differences in the deposits characteristic of opposite sides of the Sacramento, this distinction is often exaggerated.

Redding, the county seat and the principal town of the region, with a population of about 4,000, is the chief distributing point for the mines. It is about 10 miles southeast of the west end of the "crescent" and 20 miles southwest of the east end. Other important settlements have sprung up near the chief mines and smelters; among these are Keswick (now largely deserted), Coram, Kennett, Copper City, Winthrop, and Ingot. The Portland branch of the Southern Pacific Railroad crosses the western part of the region and provides outlet for the smelting towns of Keswick, Coram, and Kennett, and indirectly for the mines on the west side of the Sacramento. Two companies, the Mountain and the Mammoth, have built private railroad lines connecting their mines with their smelting plants, located respectively at Keswick and Kennett; one of these, the Mammoth, and one other, the Balaklala (which also transports for the Trinity Company), connect mine and smelter with aerial tramways. The Bully Hill and Afterthought districts have been served by the Anderson and Bellavista Railroad, a private branch from the Southern Pacific which terminates at Bellavista, from which these districts are, respectively, 15 and 12 miles distant. The Sacramento Valley and Eastern Railroad, recently completed, now gives to the mines and smelter of the Bully Hill district direct connection with the Southern Pacific; and the principal company in the Afterthought camp, it is understood, hopes soon to extend the Anderson and Bellavista line to its property.

The heavy precipitation of the rainy season of winter and early spring acts as a serious impediment to the mines dependent on wagon transportation, but in other respects the climate is on the whole favorable to efficient operation, the temperature being moderate and snowfalls light and of short duration. Abundant power is available from the streams and has been utilized to a considerable extent, through the medium of electricity, for mining operations and for other purposes. Timber for building and for use in the mines is still plentiful in the surrounding neighborhood.

HISTORY.

Mining in Shasta County began in the early fifties of last century. As in most other mining regions of California, deposits of placer gold were the first to be worked. Shortly afterwards quartz veins and other deposits in place began to receive attention, and with the early exhaustion of the richest placers, lode mining assumed first importance. The mining of precious metals still continues in a state of fluctuating activity, especially in the western part of the county.

Lode mining had hardly begun when it was recognized that at certain places copper occurs with the gold and silver. Probably the first place where the importance of this fact was realized was Copper City, in the Bully Hill district, from which shipments of gold-silver-copper ore were made in the early sixties. Though placer mining had been done on the slope below what is now the Bully Hill mine as early as 1853, it was not until the seventies that lode mining was attempted there, and even then most of the copper present (probably a considerable percentage of the ore) was wasted, as precious metals only were being sought. At about the same time similar attempts were made to work deposits in the Afterthought district. What was probably the first smelter in the region was erected there in 1875. About 1879 parts of the great gossan mass on Iron Mountain were found to give high assays for silver; at this place was opened the first really successful mine of those which have since become important as copper mines.

At a number of these places development had shown the presence of masses of sulphides lying beneath the ores then worked, but because of their lower grade and "refractory" nature little attention was bestowed on them for several years. In 1895, however, a company, now the Mountain Copper Company (Limited), secured the Iron Mountain property and began active development of the sulphide ore body. This really marks the beginning of the copper industry in Shasta County. A smelter was erected at Keswick, near the mine, and began operation early in 1896. Litigation over fumes from the smelting operations caused the company to erect a new smelter and refinery on San Francisco Bay and in 1905 to abandon smelting at its Keswick plant. In 1895 operations were resumed on the rich copper-silver ores at Bully Hill, and in 1901 a smelter was blown in. The principal mines in the Bully Hill district are now the property of the Bully Hill Copper Mining and Smelting Company, which is controlled by the General Electric Company. A small smelter was erected at Ingot, in the Afterthought district, in 1896. In 1905 a larger smelter was put into operation, but it is now idle. Development had been carried on for some time on sulphide masses at the Mammoth property, in the Little Backbone district, when in 1904 the mine was purchased by the Mammoth Copper Mining Company, a subsidiary company of the United States Smelting, Refining and Mining Company. A smelter was blown in at Kennett in 1905. In 1908 smelting was begun at the Balaklala plant at Coram, which was designed to treat the ore found in large bodies in the Balaklala and Shasta King mines. The Bully Hill and Mammoth smelters have been recently enlarged.

Large tonnages of ore have been developed in the mines of the Mammoth, Mountain, Bully Hill, Balaklala, and Trinity (Shasta King) companies, and it is understood that developments since the beginning of 1908 have added important reserves in the mines of at least the first four of these companies. Prospecting and development have been carried on at a number of other properties, and some of them have produced.

The total copper production of the region up to the end of 1909 has probably not been less than 300,000,000 pounds, by far the greater part of which has been produced since 1896. The production for 1909 is about 50,000,000 pounds, the largest annual output ever recorded. This makes the region rank as the sixth or seventh district in copper production in the United States, being exceeded only by Butte, Lake Superior, Bisbee, Bingham, Morenci, and possibly Ely.

FIELD INVESTIGATIONS.

The importance of the general region in which the Shasta County copper deposits are located as a field where much light might be gained on the preplexing problems of Pacific coast geology was long ago recognized. Geologic investigation in this region began as early as 1840 and to an increasing extent has continued up to the present time. Many workers have contributed to the knowledge that has been acquired and only the limitations of this preliminary statement prevent acknowledgment of the obligations to them under which the present study has been pursued. Even the briefest reference to the geology of this region must, however, recognize the contributions of J. S. Diller. Extending over a period of twenty-five years, his investigations have yielded a great fund of information concerning the geology of northern California. His description of the Redding quadrangle,[a] which includes nearly the whole of the copper district, was published in 1906. The rocks of that area contain, as he says, a more complete record of the geologic history of northern California than has thus far been found in any other similar area; yet their significance could have been grasped so comprehensively only by one who was able to study them in the light of intimate acquaintance with conditions throughout the surrounding country.

Realizing the importance of the copper deposits of this region, the United States Geological Survey undertook an investigation of their character in somewhat greater detail than was practicable in the areal work for the Redding folio, the maps in which are on a scale of 2 miles to the inch. Special topographic maps on a scale of 1:20,000, or a little over 3 inches to the mile, were made of the three most important copper districts—the Iron Mountain, the Little Backbone, and

[a] Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906.

the Bully Hill. (See fig. 5.) To the writer was assigned the geologic mapping of these special areas and the study of the copper deposits. Field work was carried on during the late summer and fall of 1906. In the summer of 1907 B. S. Butler accomplished most of the mapping of the Iron Mountain and Little Backbone areas and sketched the surface geology of the Afterthought district. Underground investigations were resumed by the writer in the fall of that year and were completed by its close. The conclusions presented in this paper are therefore based only on developments up to January 1, 1908.

Although the advantages of examination in detail which the more recent work enjoyed have permitted a revision of Mr. Diller's results in one or two respects, nevertheless the main structure of his conclusions remains unassailed, and the present writer is glad of this opportunity to indorse the splendid character of his work in the Redding quadrangle, performed in the face of physical obstacles and difficulties that must be experienced to be appreciated. To Mr. Butler's careful work in the field and in the office are to be credited many of the statements found here regarding petrology and the general geology of the areas west of the Sacramento.

It is at once a duty and a pleasure to mention at this place the assistance afforded in furtherance of this investigation by officers of mining companies and by others residing in the region. For the full report must be reserved more appropriate and specific acknowledgment of this generous cooperation.

TOPOGRAPHY.

GENERAL STATEMENT.

The Shasta County copper region lies near the southeastern border of an irregular and somewhat indefinite topographic province known as the Klamath Mountains. This province, consisting of several larger ranges and many groups of ridges and hills, occupies a large area in northern California and southwestern Oregon. It lies between the Coast Ranges on the west and the Cascade Range on the east—both more sharply defined provinces than the Klamath Mountains. On the southeast it breaks off rather abruptly to the great Sacramento Valley. The copper region lies among irregular groups of low mountains or high hills near the boundary with the Sacramento Valley province; the so-called copper crescent is roughly parallel with and at a distance of 5 to 10 miles from the north end of the valley. The eastern part of the region, represented by the Afterthought camp, is to be regarded as just outside of the Klamath Mountains and as comprised within the border portion of the broad and gently sloping constructional plain that flanks the western slope of the Cascade Range at this latitude. This plain has been called by Diller the piedmont plateau.

It is of interest to note that the fifth great topographic province of northern California, the Sierra Nevada, situated along the southeastern continuation of the Cascade Range axis, has probably many points of similarity, both as to geology and as to topographic development, with the portion of the Klamath Mountains here considered. It is also worthy of remark that the "gold belt" on the western slope of the Sierra, in which are located the Mother Lode and many other important mining districts, would, if projected farther to the northwest, cross the Shasta County copper region.

RELIEF.

The surface of most of the region is irregular and rough. The highest point in the three districts of which special maps were made is located in the northwest corner of the Iron Mountain area and has an elevation of about 4,550 feet. The lowest point mapped is in the same area about a mile north of its southeast corner, where the elevation is under 650 feet. Sacramento River, which lies outside the Iron Mountain area just east of this low point, has here an elevation of about 550 feet. The maximum difference of elevation in the copper region is therefore about 4,000 feet. In the Little Backbone area, which adjoins the Iron Mountain district on the northeast, the elevations range from about 700 feet at the southeast corner of the area to about 4,450 feet at Bohemotash Mountain, near the northern boundary. In the Bully Hill district the extremes of elevation are about 740 feet along Squaw Creek, near the southwest corner, and about 2,800 feet on the western slope of Horse Mountain, which, just west of the area mapped, rises to a height of 4,040 feet; almost the same elevation is attained at the northern boundary of the Bully Hill area on the southern slope of Town Mountain, whose summit, a little farther north, is 4,339 feet high. In the Afterthought district the presence of the Cascade Range piedmont plateau is indicated by a much lower range of elevations, the mines being situated about 1,200 to 1,600 feet above sea level.

The portion of the region west of the Sacramento is, on the whole, extremely rugged. Most of the higher elevations have rounded tops, and there is little tendency to form sharp peaks. The middle and especially the lower slopes of the mountains, however, are in most places very steep, forming the walls of deep, V-shaped canyons. From a number of the highest mountains extend one or more long spurs. Some of these spurs connect two or more important eminences, forming prominent ridges; others gradually decline and broaden into flanking hills. Though marked generally by crests and saddles, the tops of these spurs and ridges are of comparatively even and moderate grade and have therefore been chosen, in preference to the more circuitous and rugged valleys, as the sites for trails and roads, except where it has been possible to spend much money in the production of more even grades for roads and railroads by blasting, filling, trestles, etc. These spurs and ridges are a characteristic feature of the topography of the western districts. Iron Mountain and Little Backbone Mountain are prominent elevations, from which the districts have been named.

The greater part of the Bully Hill district consists of a scoop-shaped surface tilted toward the southeast, formed by the coalescing east and south slopes of Horse and Town mountains, respectively. Of the irregularities of this surface Bully Hill is the most prominent.

The principal workings in the Afterthought district lie along the wall of a valley cut in the piedmont plain.

DRAINAGE.

The region lies wholly within the drainage basin of Sacramento River, which is formed, near the middle of the region, by the confluence of the Pit from the east and the Little Sacramento from the north. Important tributaries to Pit River from the north are McCloud River and, farther east, cutting through the Bully Hill district, Squaw Creek. Little Backbone Creek flows southeastward into the Sacramento, and near the northern boundary of the Iron Mountain district Squaw Creek (a different stream from the one tributary to the Pit) also empties into the Sacramento from the west. Spring Creek flows southward through the Iron Mountain district and meets the Sacramento at Keswick. A small part of the Iron Mountain district is drained westward into Clear Creek, which reaches the Sacramento about 5 miles south of Redding. Little Cow Creek cuts into the piedmont plain in the Afterthought district. These streams, together with many of smaller importance, effect a thorough drainage of the region and have served to carve its present rugged features.

The development of the present topography by the erosive and aggrading power of the streams under conditions of stability or of uplift or depression of the land, and in relation to the rocks traversed, has been considered for this region especially by Diller, but this subject need not demand further attention at this place.

GENERAL GEOLOGY.

INTRODUCTORY STATEMENT.

The rocks of the Redding region outside of the Sacramento Valley province comprise a considerable number of sedimentary formations ranging in age from Middle Devonian to late Tertiary, inclusive. In this region the basement on which these sediments are supposed to have been deposited is an ancient lava formation, consisting of altered andesite, probably of early Devonian or still greater age. The various sedimentary formations extend in roughly parallel belts in a northerly direction corresponding to their strike or the intersection of their bedding planes with a horizontal plane; the dip of these stratification planes is commonly to the east, as it is in the western Sierra Nevada, farther southeast, so that the oldest rocks are at the west and the youngest ones at the east. Interbedded with the ordinary sedimentary rocks—which consist of limestones, sandstones, and shales, with some conglomerates—and forming essentially a part of the stratified series are many beds of tuff or fragmental igneous rock, formed by explosive volcanic outbursts, and some lavas of more massive character. These products of volcanic eruption constitute the oldest and the youngest rocks of the region and were also formed in nearly every intervening period. In few other regions does there exist evidence of the persistent recurrence of volcanic activity over such long eras of time.

The relations of the various members of the stratified series have been modified and complicated by the intrusion into them of several kinds of igneous rocks in various forms, comprising stocks, dikes, and sills. The surface relations have been further obscured in some places by coverings of lava of much later age than most of the rocks.

The copper region, viewed as a unit, crosses the strike of the sedimentary rocks and contains representatives of nearly every one of the formations outlined above. For a thorough understanding of the geology of the region it would be necessary to have some description of the full stratigraphic sequence, but, although copper is known to occur in some other formations, the present article will deal only with those rocks that are found within the four principal districts of the copper region—Iron Mountain, Little Backbone, Bully Hill, and Afterthought.

SEDIMENTARY ROCKS.

KENNETT FORMATION.

The Kennett formation consists chiefly of black fissile shale, with scattered lenses of light-gray limestone that stand out strikingly and numerous gray or yellowish beds of tuffaceous material. From abundant fossils contained in the limestone the age of the formation is determined as Middle Devonian. It occurs only as irregular, separated erosion remnants of what was once probably a large and continuous sheet. Its maximum known thickness is 865 feet, but at most places it is much thinner. Within the areas considered it is present only in the eastern part of the Little Backbone district. Some of the largest masses occupy the crests of spurs or ridges, but others are well down the slopes and were evidently entirely inclosed in the adjoining rock, alaskite porphyry, until revealed by erosion. The Kennett formation has no connection with known copper deposits, though small blocks of it are encountered in the workings of one of the mines, the Mammoth.

BRAGDON FORMATION.

The Bragdon formation consists chiefly of black and gray shales, with thin interbedded layers of tuff and sandstone, and especially in its lower portion as exposed in this region, bands of conglomerate. The Bragdon is known to overlie the Kennett unconformably, but in the special areas mapped the two formations are not adjacent, the Bragdon resting everywhere in a tilted position on the alaskite porphyry. The conglomerate contains many fragments of the Kennett formation and also of the basal altered andesite, though within the areas of the special maps none but sedimentary fragments were observed. Fossils found in the shale and sandstone beds show the age of the Bragdon to be Mississippian, or lower Carboniferous. The formation is present in the northwest corner of both the Little Backbone and Iron Mountain areas, but the Bragdon rocks at these places are only parts of the thinning edge of a large mass several thousand feet thick that extends northward and westward for several miles. Patches of shale or tuff probably belonging to this formation are included in the alaskite porphyry, as for instance near the summit of Iron Mountain. In only one place is the Bragdon connected with copper deposits; at the Lone Star claim, near the western edge of the Iron Mountain area, copper ore is found along the contact of Bragdon shale and alaskite porphyry, the ore occurring in both rocks.

PIT FORMATION.

Like the two formations already described, the Pit formation consists chiefly of shales, black to gray in color and mostly of fine grain. It also contains in considerable abundance interbedded layers of volcanic tuff. Fossils are not common, but such as have been found indicate that the rocks were deposited in the later half of the Triassic period. The total thickness is believed to be over 2,000 feet, but only a part of the formation is present in the mining districts. Rocks of this formation occur in the Bully Hill district as large and small blocks resting upon or partly embedded in the alaskite porphyry. A similar relation exists in the Afterthought district. Copper ore occurs in the shale only in the Afterthought district, where the ores extend from the alaskite porphyry into the shale. Small blocks of the shale are also found in the Bully Hill mine, but are not related to any known ore bodies.

IGNEOUS ROCKS.

META-ANDESITE.

A dark-greenish rock of andesitic nature, but considerably altered from its original composition, and therefore called meta-andesite, occurs over a considerable area in the southeastern part of the Iron Mountain district and in smaller patches in the southwestern and northeastern parts. It has been named the Copley meta-andesite by Diller. It was a series of flows of porous or cellular lava, but in general the individual flows are not evident within the Iron Mountain district, and most of the cells have been filled with secondary minerals, principally quartz, epidote, chlorite, and calcite, giving rise to an amygdaloidal structure. Beds of tuff occur sparingly and in places the massive lava has been brecciated. Its age can not be determined from data gained within the Iron Mountain or Little Backbone areas, but from observations elsewhere Diller finds that it is older than Middle Devonian, as it underlies both the Kennett and the Bragdon formations and by its erosion has furnished part of the material of which they are composed. No known copper deposits occur in this rock, but it is cut by numerous quartz veins, some of which carry gold in commercial quantity.

ANDESITE.

The greater part of Horse and Town mountains, near the Bully Hill district, as well as of other mountains farther north, is composed of a dark-greenish rock having the composition of andesite. It has been named Dekkas andesite by Diller. It is generally rather massive and in many places is distinctly porphyritic, containing many small light-colored feldspar crystals in a dark-green, fine-grained groundmass. Here and there, however, scoriaceous and tuffaceous varieties are seen and indicate the surficial character of the rock. The formation unconformably overlies upper Carboniferous rocks and underlies and in part grades into the tuffs and shales of the Pit formation; it is therefore regarded as of early Triassic age. Its maximum thickness is about 1,000 feet, but considerably less than this is exposed in the Bully Hill district, whose northern and northwestern parts it occupies in irregular masses. Some prospecting has been done in this rock in the northern and western parts of the district and copper minerals are known to occur in it on the east side of the saddle between Horse and Town mountains, but in general it does not hold an important relation to the copper deposits.

ALASKITE PORPHYRY.

A rock of porphyritic texture and of a composition rather similar to that of granite occurs in two general localities in the copper region and has been named alaskite porphyry. It holds sparingly small phenocrysts of quartz and feldspar in a predominant groundmass that, when fresh, is of dark-gray color, but in most places in the region the rock of this type is considerably altered and is bleached to lighter shades of gray, green, yellow, or pink. It is also much cut by joints and shearing planes. It weathers generally in rough, bold outcrops and forms steep slopes on which little soil from the complete disintegration of the rock can accumulate. Rock of this type is intimately associated with all the known copper deposits of importance and for that reason it merits rather fuller description than the other rocks.

From the results of examination in a degree of detail commensurate with folio mapping on a scale of 2 miles to the inch, Diller concluded that these rocks were surface flows and were therefore necessarily older than the overlying sedimentary formations, though from his various published statements regarding these relations it may be inferred that such a conclusion was not reached without some hesitation. Because of their composition he called them rhyolite; the mass west of the Sacramento, which extends northeastward through the middle of the Iron Mountain and Little Backbone districts, he named the "Balaklala rhyolite," and the group of irregular masses that reaches from the Bully Hill district to the Afterthought district he named the "Bully Hill rhyolite." The "Balaklala rhyolite" he considered as underlying, and therefore older than the Kennett formation (Middle Devonian). The "Bully Hill rhyolite" he regarded as generally underlying the Pit formation (Middle or late Triassic), though in places it cuts the Pit rocks; he placed it as older than the uppermost Triassic.

The more recent study, enjoying opportunity for examination in much greater detail and profiting by the final conclusions of Diller's investigation, has resulted in some modification of the views outlined above. It now appears that the rocks of both the "Balaklala" and "Bully Hill" types are intrusive [a] into the surrounding rocks. The direct evidence of this intrusive nature of the alaskite porphyry may be summarized as follows: (1) Dikes, sills, and other intrusive masses of it cut the surrounding rocks—the Copley meta-andesite and the Devonian (Kennett) and Carboniferous (Bragdon) sediments in the western districts and the Dekkas andesite and the Triassic (Pit) sediments in the eastern districts. (2) At many places along the contact with other rocks the alaskite porphyry is of finer grain than elsewhere. (3) The overlying or adjoining rocks are brecciated at many places along the contact with the alaskite porphyry and at most such points the shales [b] are indurated and more or less metamorphosed.

[a] This view had previously been implied by H. W. Fairbanks (Rept. California State Min. Bur., vol. 11, 1892, pp. 32, 46, etc.).

[b] At all points within the special areas studied the limestones of the Kennett formation are separated from the alaskite porphyry by a considerable thickness of shale, and doubtless for this reason no positive evidence of contact metamorphism has been found in the limestone.

(4) Masses of the surrounding formations are inclosed in the alaskite porphyry. These masses were evidently torn from the main bodies of the corresponding rocks by the invading alaskite porphyry magma and were enveloped in it before it solidified; such included masses consist both of large blocks, several thousand square feet in area, and of much smaller bodies, ranging down to small included fragments of shale where that rock has been brecciated at the contact with the alaskite porphyry. (5) In places the sedimentary formations have been distorted by the intrusive masses of alaskite porphyry and forced into forms that, before erosion, were doubtless arches or domes. (6) The rock is holocrystalline, no glass nor its devitrified equivalent having been found in the scores of thin sections examined from many localities; and it would seem unnatural for a rock so high in silica and so low in bivalent bases to develop holocrystalline texture throughout if it were of surface origin. Indirect evidence pointing in the same direction is afforded by the close relation as to age and source that is believed to exist between the alaskite porphyry and a rock, quartz diorite, concerning whose intrusive nature there is no question.

The recent investigation also shows that the rock in the Iron Mountain and Little Backbone districts is practically indentical in all respects with that in the Bully Hill and Afterthought districts. Almost every statement concerning the rock of the one locality would apply equally well to that of the other. The identity is strongly indicated by field relations and megascopic character and is established beyond doubt by the results of microscopic and chemical investigation. The unusual chemical character of the rock and the similar character of the masses in the eastern and western sections of the region may be shown by analyses 1 and 2 following, which were made by George Steiger on typical specimens of the freshest material. Analyses 3 and 4 represent alaskite from other regions.

Analyses of alaskite porphyry.

	1.	2.	3.	4.		1.	2.	3.	4.
SiO_2	80.09	78.50	77.33	76.04	ZrO_2	.01	None.	....	....
Al_2O_3	10.80	11.50	12.55	....	CO_2	None.	None.	None.	....
Fe_2O_3	1.07	.11	.91	....	P_2O_5	.04	.03	Trace.	....
FeO	.83	1.82		....	SO_3	None.	None.	....	....
MgO	.58	.46	.10	....	S	None.	.13	....	....
CaO	.38	.50	.17	.46	MnO	.02	.03	Trace.	....
Na_2O	5.60	6.04	3.19	7.58	BaO	None.	None.	Trace.	....
K_2O	None.	None.	4.80	.07	SrO	None.	None.	Trace.	....
H_2O-	.24	.30	.15	....	Li_2O	....	....	Trace.	....
H_2O+	.52	.82	.53	....					
TiO_2	.16	.27	.09	....		100.34	100.51	99.82	

1. Dark-gray alaskite porphyry from surface above Shasta King mine, Iron Mountain district.
2. Dark-gray alaskite porphyry from point near main tunnel, Bully Hill mine, Bully Hill district.
3. Alaskite from Tordrillo Mountains, Alaska. H. N. Stokes, analyst. Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 231.
4. Alaskite from Silver Peak district, Nevada. Partial analysis made for H. W. Turner by George Steiger and cited by Spurr, J. E., Prof. Paper, U. S. Geol. Survey, No. 55, 1906, p. 23.

These and other analyses show that the rock is of fairly constant composition over wide areas, though here and there occur transitions to another type, as will be shown shortly. The particularly noteworthy features in the composition of these rocks are comparatively high soda, potash very low or entirely wanting, low magnesia and iron, and generally low lime, though this last-named constituent is more variable than the others. Calculation of the analyses shows that quartz and feldspar together make up between 92 and 95 per cent of the rock, the feldspar generally predominating slightly. The feldspar is mostly albite, the percentage of calcium feldspar being usually very low. The rock may be considered as a silica-rich granite porphyry in which the customary potash feldspar (orthoclase) is replaced by soda feldspar (albite). It appears to correspond most closely, however, to the type alaskite established by Spurr [a] and defined as consisting essentially of quartz and alkali feldspar with but small amounts of other minerals. The rocks originally given the name alaskite by Spurr all contain an important percentage of potash, along with soda, but there seems to be nothing in his definition that would exclude quartz-feldspar rocks in which the feldspar is chiefly albite, and he later included in the group the rock from Silver Peak (see analysis 4), in which the soda is high and the potash very low.

The phenocrysts of the rock, consisting of quartz, albite, and rarely oligoclase-albite, are generally of small size, though in a few places they may attain a diameter of one-quarter inch or even more; in such places the groundmass also commonly increases in coarseness. Much of the albite is untwinned. The fine-grained groundmass consists of a microgranular mixture of quartz and feldspar, part of which is twinned and part untwinned. Fine shreddy grains of magnetite and small particles of chlorite and of epidote that were probably derived from original flakes of biotite constitute the chief accessory constituents, but are nowhere present in important amounts. Apatite, titanite, and zircon exist sparingly as small crystals. Though of comparatively constant composition, the rock is somewhat variable in texture and appearance, especially in the area west of the Sacramento. For the most part it is distinctly porphyritic and in places is of fairly coarse grain, but locally it is dense and fine grained, doubtless as a result of differences in conditions of solidification. The chief differences in the appearance of the rock at various points, however, are the result of secondary causes. Over large areas the rock is much sheared and differences of alteration and weathering, emphasized by and partly dependent on this shearing, give it in places a banded aspect. These variations in appearance somewhat resemble those of a series of lava beds but are of different origin.

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[a] Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 231.

As the alaskite porphyry is intrusive, its age is not necessarily fixed by that of the surrounding rocks. As the different bodies are without doubt products of eruption from a single magmatic source and within the same general period of time, and as in places the porphyry cuts upper Triassic sediments, it follows that the rock as a whole is at least as young as upper Triassic. Direct stratigraphic evidence further limiting its age is not found in the copper districts and probably is not present in the Redding region, but on the grounds of petrologic relationship with the quartz diorite, next to be described, which is believed to have been intruded soon after the alaskite porphyry and whose age is somewhat more readily inferred, it is thought by the writer that the intrusion of the alaskite porphyry, as well as of the quartz diorite and certain other rocks of the general region, were events that brought the Jurassic period to a close. This view would seem to gain support from generally analogous conditions existing in the Sierra Nevada.

The alaskite porphyry is the country rock of all the important copper deposits except in the few places where the ore bodies extend beyond its confines into adjoining shales. The economic significance of the fact that the rock exists as intrusive masses instead of as bedded flows will later be referred to.

QUARTZ DIORITE.

A rock which resembles granite in appearance but whose feldspars are almost entirely of the soda-lime series forms an important mass in the southeast corner of the Iron Mountain district and extends in greater area farther south. It disintegrates rather readily and forms a granular soil on slopes that are gentler and smoother than those which characterize the alaskite porphyry.

The rock is very similar in appearance to the coarser varieties of the alaskite porphyry, to all of which it shows chemical and mineralogical affinities. It cuts the alaskite porphyry, but the contact is in general difficult of precise location because of transitional facies near the boundary. It is believed that the quartz diorite was a later and somewhat differentiated product of eruption from the same general magmatic source that furnished the alaskite porphyry, but that its intrusion so closely followed that of the porphyritic rock that it found the region to which it ascended in a somewhat heated condition and therefore, cooling more slowly, it developed coarser and more even grain than its older and more siliceous porphyritic relative. It is regarded as significant, also, that the coarsest of the alaskite porphyry, in the vicinity of the Uncle Sam mine and elsewhere, which is wholly impossible of separation from the normal variety surrounding it, is closely similar in appearance and mode of weathering to the quartz diorite (though the extent of alteration at most of these places prevents absolute proof of further identity by microscopical or chemical means) and is characterized, as is the quartz diorite itself, by the relative abundance in it of basic dikes and quartz veins as compared with the normal alaskite porphyry. Feldspar, quartz, and hornblende, stated in order of decreasing importance, are the chief components of the rock. Biotite may also have been present, but if so it has been completely altered. Most of the feldspar is so altered that the more precise methods of determination can not be applied to it. A considerable portion of it is unstriated and in extinction angle and refractive index corresponds to albite. Part of this contains, in microperthitic arrangement, a little orthoclase, which probably accounts for all the potash contained in the rock. Some of the twinned feldspar is also albite, but most of it appears to have a composition near andesine. Magnetite, titanite, and a little apatite are the accessory minerals.

Copper deposits are not known in the quartz diorite, but quartz veins occurring in it have been worked for gold at numerous places within and outside of the Iron Mountain area.

DIKE ROCKS.

Around the outskirts of the alaskite porphyry and the quartz diorite are dikes and sills similar in composition to these larger masses, of which they are but smaller branches or apophyses. In connection with the quartz diorite occur sparingly pegmatitic dikes of rather irregular form and somewhat more acidic character than the parent quartz diorite; these pegmatites in places pass over into siliceous masses that are virtually quartz veins and carry sulphides. Somewhat more common than the types already mentioned are dikes that cut either the quartz diorite and alaskite porphyry or the surrounding rocks, or both. Most of these dikes are dark, basic, and as a rule easily susceptible to weathering agencies. They range, however, from rocks with a composition close to that of the alaskite porphyry to rocks of very basic types consisting chiefly of ferromagnesian minerals, mainly pyroxene and augite. These extremes are connected by intervening types, and from both chemical and mineralogical considerations the dikes can best be regarded as a series of differentiation products from the magma that is most abundantly represented by the alaskite porphyry and the quartz diorite. As already implied, the basic dikes are most common in or near the quartz diorite and the quartz dioritic phase of the alaskite porphyry. In the Bully Hill mine the main ore zone parallels one of these basic dikes and at certain points the rock of the dike is more or less completely replaced by ore. In the Iron Mountain district quartz veins have formed at several places alongside of such dikes.

STRUCTURE AND METAMORPHISM.

GENERAL STRUCTURE.

In the copper districts alone satisfactory and adequate ideas of broad structural features could hardly be gained because of the relatively small areal importance of sedimentary rocks, by means of which structure is best revealed. The general structure of the region included within the Redding quadrangle is known, however, and aids greatly in interpreting the geologic relations in the vicinity of the copper deposits. As already outlined, the rocks of the Redding region have in general a northerly strike and a dip to the east, except where this simple structure has been modified by intrusion. It is believed that this eastward tilting of the strata was effected at about the close of the Jurassic period or at about the time of intrusion of the alaskite porphyry and quartz diorite. The shape which the masses of these intrusive rocks assumed was undoubtedly influenced by this generally conformable relation of the sedimentary rocks. Consequently, instead of forming stocks or batholiths that cut indiscriminately the various older rocks, the intrusive masses were limited in their upward invasion by certain thick and tough yet somewhat pliant shale formations which, in a broad way, were raised into domes or arches, though locally they were more or less shattered and surrounded by the intrusive rocks. Thus in the western districts the Kennett and Bragdon formations have been arched up by the alaskite porphyry, and in the eastern districts the Pit formation has been deformed by it. There is thus an approach toward laccolithic conditions, though it is not certain that true laccolith structure is present. A large part of the sedimentary rock entering into these structures has of course been later removed by erosion.

The possibility that the copper-bearing rock, alaskite porphyry, gives way at a comparatively shallow depth to some underlying and probably barren formation is a question of much economic significance. The chances that this actually takes place are much smaller if the alaskite porphyry exists as intrusive masses than if the rock consists of a series of flows, as is at present commonly believed in the copper region. There is no reason to suppose that the alaskite porphyry gives out at less depth than that to which mining—to judge from present developments—would naturally be carried. This statement probably applies especially to the districts west of the Sacramento.

Except for the bending of the strata caused by intrusion, as above noted, broad folding is uncommon and unimportant in the region, though minor plication of the shales is seen at numerous places. Faulting has little effect on the general structure of the rocks, but some faults are noteworthy because they displace ore bodies, and, as will be shown on a later page, many of the boundaries of the copper ore bodies may be related to faults.

METAMORPHISM AND MINOR STRUCTURE.

All the rocks of the copper region are more or less altered from their original condition, and many of them have suffered severely. The alteration has been brought about by both chemical and mechanical means and has taken place within the rock masses, as the result of deep-seated disturbance of chemical and mechanical equilibrium. Near the surface weathering has superimposed still further chemical alteration of the rocks.

The deep-seated alteration has most affected the igneous rocks, especially the alaskite porphyry. This rock is in most places so changed from its initial character that only rarely can material be found sufficiently fresh for reliable investigation and analysis. The mechanical or dynamic metamorphism resulted in brecciation, shearing, and the development of incipient gneissic or schistose structure.

As expressed by mineral development, the chemical change in the the alaskite porphyry consisted chiefly in the production of sericite,[a] secondary quartz, chlorite, metallic sulphides, carbonates, and epidote, stated in about the order of their importance over wide areas, but in and close to the copper ore bodies the proportions of these minerals are changed and some additional species, like barite and anhydrite, were developed. From the chemical work thus far completed it appears that the alteration results most commonly in a reduction of the silica content of the rock, with a corresponding increase in proportions of some of the oxides, most marked in alumina. The apparently paradoxical decrease in silica with increase in quartz may find explanation in the fact that in the transformation of albite into sericite a considerable amount of free silica is formed. In certain places a net gain in total silica results from the alteration. The original iron of the rock seems to be largely removed, but locally pyrite is introduced in varying amount. Almost invariably the percentage of magnesia is noticeably increased, though it nowhere reaches an important amount. This element seems to be added directly to the rock, mainly in the form of chlorite, though dolomitic carbonate is present in some specimens and may be, in very small quantities, more widespread than is evident. In general the small percentage of lime held in the rock is further reduced on alteration, but in and near the ore bodies calcite is rather plentiful. The high soda content of the fresh rock is much lowered by the alteration process; in its place potash is deposited, but not in quantity corresponding to the soda removed.

[a] Later work by B. S. Butler indicates that part of the shreddy or fibrous micaceous alteration product may be paragonite, the soda mica, which is analogous to the potash mica, sericite, the fibrous form of muscovite.

The percentage of combined water is of course higher in the altered than in the fresh rocks.

Both the chemical and the mechanical changes are believed to have connection with the intrusion of the alaskite porphyry itself; the solutions that brought about the change in composition are believed to have been residual mother liquors from which the alaskite porphyry, as well as the quartz diorite and the dikes, had already separated by crystallization, and the brecciation and shearing are believed to have resulted from stresses set up by contraction of the cooling rock mass, aided perhaps by adjustments that followed the transference of matter from one point to another when intrusion took place. The idea that the strains and movements closely followed the intrusion of the alaskite porphyry is supported by the facts that the shearing is largely confined to the alaskite porphyry itself, persisting but little in adjoining rocks, and that the quartz diorite and the dikes, whose intrusion is believed to have closely followed that of the alaskite porphyry, were nevertheless too late to participate to any important extent in these shearing movements.

The chemical and mechanical changes in the alaskite porphyry undoubtedly have intimate genetic connection with the deposits of copper ore, for the ore bodies are simply portions of the rock that have suffered extreme alteration, amounting locally to complete replacement of the rock by new minerals, chiefly sulphides; and this extreme alteration is believed to have been permitted by the shearing and crushing of the rock, which have not only afforded channels for the ingress of the altering and ore-bearing solutions, but also rendered the rock more susceptible to attack by these solutions. The material of the quartz veins is believed to have been derived from similar solutions. The localities of most vigorous metamorphism will be indicated and the processes themselves will receive further consideration in the discussion of the copper deposits.

In a lesser degree silicification, sericitization, pyritization, etc., have affected the quartz diorite also over large areas. In the andesite and meta-andesite the development of silica, carbonates, chlorite, and epidote has been most important. The partial metamorphism of the shales at the contacts with alaskite porphyry has already been mentioned.

THE COPPER DEPOSITS.

GENERAL FEATURES.

The important copper deposits of the Shasta County region consist of large masses of pyritic ore, surrounded in most places by alaskite porphyry but here and there extending into shale. The ores are of medium richness, yielding at present an average of about 3 to 3½ per cent of copper and $1.50 to $2 per ton in precious metals, generally about equally divided between gold and silver. The largest deposits have been found in the western half of the district, and some of these are among the great sulphide ore bodies of the world. Single ore masses have maximum dimensions of 1,200 feet in length, 300 feet in width, and nearly 300 feet in thickness. In few places is this maximum thickness attained, the average thickness being much smaller, though on the other hand some ore bodies of less than the maximum length are over 300 feet in width. As only 7 to 8 cubic feet of the massive sulphide ore in place is required to make a ton, it can readily be seen that these great ore bodies contain large tonnages; in several the tonnage runs into the millions, and the Iron Mountain ore body, before a great part of it was converted into gossan, probably contained at least 20,000,000 tons, exclusive of the unknown but necessarily large amount that has been eroded away. Masses of much smaller size also occur west of the Sacramento, and in the eastern districts, Bully Hill and Afterthought, smaller and less regular ore bodies are the rule.

In the rugged western districts tunnels afford convenient access to the ore bodies, most of which lie comparatively flat and within a few hundred feet of the surface. In the eastern districts, where the topography is more even and the ore deposits extend deeper, shafts are employed in addition to tunnels. The compact shape of most of the ore bodies allows development and operation with a minimum of drifting, and though some of the mines have thousands of feet of such openings, the amount in relation to the tonnage of ore opened is much lower than in many other districts. The deepest working in the district at the beginning of 1908 was the 970-foot level in the Bully Hill mine. At the present time (January 1, 1910) it is learned that both the Bully Hill and the Rising Star shafts have attained a depth of about 1,100 feet below the outcrops. In the largest ore bodies some of the cheaper mining methods, such as slicing and caving, have been generally adopted in place of the earlier system of square setting and filling. All of the ore is smelted without concentration and for the most part without roasting. Owing to the high percentage of sulphur contained in the ore, the coke required can be reduced to a much lower quantity than was used when roasting was employed.

The principal deposits are grouped in three localities or zones. One of these zones lies west of the Sacramento in the Iron Mountain and Little Backbone districts and includes, along a general northeasterly line, the Iron Mountain, Hornet, Balaklala, Shasta King, Mammoth, and Golinsky mines; at a number of other points along the same general belt either gossan or smaller masses of sulphide ore occur and at the Sugarloaf, Hardtack, King Copper, Spread Eagle, Friday-

Louden, and Summit properties they have received more or less development. A second zone extends a little east of north in the Bully Hill district and includes the Copper City, Rising Star, and Bully Hill mines, together with a number of prospects. The third zone, of smaller importance, includes the Afterthought and Donkey mines, in the Afterthought district. In the following pages only general features of the ore deposits of the region will be referred to, and no attempt whatever will be made to describe individual deposits in detail.

CHARACTER OF THE DEPOSITS.

DISTRIBUTION, SHAPE, AND STRUCTURE.

The ore bodies themselves are in general irregularly tabular. The larger number are of definite extent and, though for the most part very irregular, can best be referred to as lenses. Here and there, however, two or more of these bodies or lenses are present in the same general plane, which, outside of their confines, is more or less impregnated with minerals of the ore bodies and which might thus be regarded as a lode, of which the ore lenses constitute pay shoots.

All the ore bodies represent, not the filling of cavities existing before the entrance of the ore or developed during its formation, but rather a more or less complete replacement of the same kind of rock as that by which they are surrounded.[a] In this way the various components of the rock have been removed and their places occupied immediately by the minerals of the ore bodies. The evidences of this replacement are many and obvious. The most common and convincing are (1) the gradual transition from wall rock to solid sulphide ore observed in many places; of the same nature are the countless localities in the alaskite porphyry, both near and distant from masses of commercial ore, where the rock has been impregnated with sulphides or other minerals of the ore bodies, but not in sufficient amount to obscure its identity; (2) the presence in the ore of crushed fragments or remnants of wall rock only partly replaced, and of similar but larger masses or horses which for the most part have the same direction of shearing or schistosity as is shown in the main walls of the ore body and which doubtless therefore occupy the same position that they held before the introduction of the ore; (3) the retention at places in the ore of structure characteristic of the wall rock (pseudomorphous replacement); (4) the difficulty of conceiving how spaces, some of them hundreds of feet in every dimension, could have been formed and kept open even long enough for the ores to be deposited.

In the Iron Mountain ore body a specific and beautiful example proving replacement consists of massive sulphide ore in which the

[a] There are local exceptions to this in which basic dike rock and shale have been replaced.

phenocrysts or prominent crystals of quartz belonging to the alaskite porphyry are contained in their original condition and probably in their original position, but constitute the only portion or component of the rock not replaced by sulphides;[a] the same condition is seen in some of the gossan between the Iron Mountain and Hornet mines. Such occurrences, however, have not been observed at other parts of the region and are exceptional at Iron Mountain.

The reasons for the distribution of the ore deposits of the region are questions that have much concerned both geologic investigators and operators and prospectors in the region. The conditions that governed the replacement of the alaskite porphyry by ore and determined why some parts of the rock should be completely converted into ore, why others should be only partly replaced, and why still others should be nearly or quite unaffected are not plainly revealed and can not be determined directly from observation. The deductions thus far reached and expressed below concerning these conditions are not regarded as thoroughly established or altogether satisfactory, though they serve to explain some of the perplexing features and though no other hypothesis worthy of serious consideration has suggested itself. It may be safely averred that variations in the original composition of the rock did not influence the replacement in any important degree. The generally constant composition of the alaskite porphyry masses is evidence against such an idea, and the indiscriminate manner in which the ores have replaced the siliceous alaskite porphyry and a basic dike in the Bully Hill mine indicates that chemical composition was not the determining factor of replacement.

The localities where ore was deposited in place of the rock originally present are believed to have been determined primarily by the physical or mechanical condition of the rock at such places. It is a fact that can not escape immediate observation that in or around the places where ore has been deposited the rock is in a particularly crushed or sheared condition and in many localities is practically a schist. This shattering and shearing of the alaskite porphyry has already been referred to under the heading "General geology." The belt containing copper deposits that extends from Iron Mountain northeastward to the Golinsky mine is a zone in which shearing has been, on the whole, much more intense than in the regions immediately southeast and northwest of it. Similarly the principal deposits in the Bully Hill district lie in a zone of intense shearing and the rock at both mines in the Afterthought district is also much sheared. The trend of the zone crossing the Iron Mountain and Little Backbone districts and of the shear zone of the Bully Hill district corresponds to the general direction along which the shearing movements

[a] See Campbell, D. F., Min. and Sci. Press, vol. 94, 1907, p. 29.

took place and therefore coincides with the general strike of foliation or schistosity of the rock, though there are local deviations of more or less magnitude from such general directions. The trend of each of these shear zones also corresponds rather closely with and is probably in some way related to the direction of longest dimension of the alaskite porphyry stock in which the zone occurs. This shearing is believed to have taken place just after the intrusion and consolidation of that rock and shortly before the formation of the ores. In the Afterthought district local influences, particularly the proximity of a large mass of shale, have apparently affected the direction of shearing. Within these general zones or localities of shearing the extent of shattering or comminution of the rock is not equal. Whether the differences are due to unlike rigidity of various portions of the rock mass or to lack of uniformity in the forces applied is not apparent. It is not unlikely that both factors existed. At any rate, the resulting strains range from a simple fracturing or shattering of the rock through a sheared or foliated condition to a state of intense brecciation, in which the rock has been ground up into small fragments or particles. In the last-mentioned condition, although there has probably been little relative displacement of adjacent particles, the foliated or schistose structure is present in extreme degree, though not always so evident in the hand specimen as in portions that have undergone less shearing. The intermediate condition in which the rock has been drawn out into a noticeably gneissic or schistose structure is most common within the shear zones, and the two extremes are local exceptions.

As implied on an earlier page, it is this shattering of the rock that is believed to have allowed the entrance of the solutions from which the ores were deposited. Where the rock was little broken it was relatively impervious; where most shattered or brecciated it was naturally most pervious and permitted with greatest readiness the ingress and transmission of the ore-bearing solutions. More than this, however, the finely comminuted rock, exposing to the solutions an area of surface far greater in proportion to its mass than that afforded by the less shattered portions, was in corresponding or even greater degree susceptible to chemical attack by these solutions and therefore could be replaced by the ore materials with comparative readiness, while the more massive rock not only failed to receive a proportionate quantity of the ore-bearing solutions but also was not in condition to be easily attacked by such as did reach it. Portions that had undergone intermediate degrees of brecciation would naturally experience a degree of replacement by ore materials intermediate between that of the most comminuted parts and that of the most massive parts. Microscopic study of a great number of thin sections of the ores and of the wall rocks more or less impregnated by ore minerals appears to substantiate the foregoing hypothesis, though from the very fact that the most complete replacement has generally obscured and made difficult of observation the condition in which the replaced rock existed, the evidence is not wholly conclusive.

Another and related feature concerning the shape and disposition of the ore bodies is their relation to the walls or adjoining masses of rock. This relation may be exhibited in any one of three ways. (1) In numerous places there is a gradual transition from country rock to ore, the percentage of minerals that constitute the ore increasing progressively over a distance of several feet or even scores of feet. In such places the direction of foliation of the wall rock generally corresponds locally with the outlines of the ore body. (2) In comparatively few places the change from solid ore to barren or little-mineralized country rock is abrupt, but the contact between the two is tight or "frozen," indicating, as in the first case just mentioned, that the ore was formed adjacent to the same portion of country rock as now adjoins it. (3) In many cases, especially in the deposits west of the Sacramento, the solid ore abuts abruptly against a sharp fracture or "clean" wall, on the other side of which is found "waste"—that is, country rock containing much less or very little or perhaps even none of the sulphides. The nature of these breaks suggests that they are faults, and such some undoubtedly are, carrying a gouge in which are ground-up fragments of both ore and wall rock and bounded by somewhat shattered ore and country rock. One of the best shown of these faults that cut the ore and are therefore of later age than its deposition is that which is encountered in some of the old Windy Camp workings of the Balaklala mine and has divided the ore body into two parts.

Along many of the sharp walls above mentioned the ore and in some places the country rock also may be no more broken and shattered than away from these walls, and though a little clayey material is present in the fracture, this is in many places so thin that the point of a miner's candlestick or even a knife blade can barely be inserted between the ore and the country rock, and this close relation of the ore and the wall may be found at every place along the whole side of an ore body where development has exposed the wall. Where the gouge along such fractures is thicker it proves in many places to contain no recognizable fragments of either the ore or the wall rock, but instead not uncommonly holds more or less perfect crystals of pyrite. At most points the actual surface of the sulphide ore, against which this gouge rests, is in a broad way even and flat, but in minute detail is rough and composed of portions of the faces of very small crystals of sulphide. There are places, however, where the face of the ore adjoining these fractures is scoured, and even very highly polished. In some places, particularly in the Mammoth mine, small lenses of ore in unshattered and unworn condition are found in some of the thickest bands of gouge; in other places the wall rock adjoining these fractures is locally impregnated to some extent by sulphide minerals. Many of these fractures, instead of being approximate planes, are more or less curved and in places are so irregular that they may almost be described as billowy. It is believed that these fractures also are planes along which movement has taken place—that is, they are faults—but they are believed to be different in time and mode of formation from the postmineral faulting, such as that already referred to as occurring in the Balaklala mine.

The explanation of the character of these earlier faults and of the other kinds of boundaries between the ore and the wall rock is believed to depend on the hypothesis outlined above, namely, that the ores were formed at places of most intense shattering and comminution of the rock. It is believed that where the ore and wall rock grade into each other, as noted above, in (1), what is now ore was originally very finely brecciated alaskite porphyry and what is now little-impregnated wall rock was sparingly replaced by ore because it was less permeable and susceptible of attack, while the intervening material showing an intermediate degree of impregnation by the ore minerals was of correspondingly intermediate character as regards fineness of its fragments. It is also believed that at other places instead of a gradual transition from a mass of very finely ground rock into that less affected by shattering, areas of finely brecciated material were brought abruptly, probably through the medium of faulting, against faces of much more massive rock, as in (3). Movements along these sharply defined faces resulted in the development of more or less clayey material or gouge. Then when the ore-bearing solutions permeated through the most shattered portions, they extended as far as these sharp fractures or fault planes, but, partly because of the impervious layer of gouge and partly because the rock on the other side of these planes was dense and but slightly permeable, they were confined to the region of the most shattered material, which they replaced more or less completely. In this way solid ore was formed on one side of the old fault plane and country rock little affected by the ore-bearing solutions is found on the other side, no displacement having occurred along the fault after the formation of the ore. The polishing of the faces of sulphide ore that is seen along such fault planes at some places is probably to be explained by slight oscillatory movements, and probably could not have been effected by the grinding that would attend important displacement of one side of the fault, for such movement would certainly have resulted in greater disturbances of the ore than have actually taken place. The small lenses of ore and the crystals of pyrite found in the bands of gouge are believed to be direct replacements either of a portion of the gouge or of some masses of probably shattered wall rock contained in it; and the local impregnations by sulphides of the country rock on the side of the fault planes opposite from the main ore bodies are believed to represent those comparatively rare places where the ore solutions penetrated through the gouge layer and were able to attack and to partly replace country rock on the other side. The kind of boundary between ore and inclosing rock, indicated in (2)—namely, that in which solid ore changes abruptly into little-altered rock without any separating fracture—is believed to represent those places where so little gouge was developed at the boundary between massive rock and much-brecciated material that the ore-forming solutions extended up to the very face of the massive rock and began to attack its surface and replace it with ore, but were unable to penetrate into it.

In addition to the evidence which was obtained by means of the microscope regarding the relative degrees of shattering undergone by the alaskite porphyry and which, though not final or conclusive, tends to support the view indicated above, there is another kind of evidence that points in the same direction. Quartz veins carrying chalcopyrite and in places enough gold to make their extraction profitable are not uncommon in the region. They cut the alaskite porphyry and some of them cut the ore bodies. They are believed to have been formed immediately after the formation of the large sulphide bodies and to have derived their materials from the same general source that furnished the copper ores. In at least two mines, the Mammoth and the Balaklala, veins of this kind cut through the alaskite porphyry wall rock, across fault gouge and into the massive sulphide ore bodies. Two of the quartz veins sent out side branches into the gouge, but except for a small amount of fracturing at the fault plane, due to slight adjustments of the two sides of the fault, none of the quartz veins was displaced at the fault. If, as seems probable, the formation of these quartz veins closely followed that of the sulphide ore, their direct passage without displacement across fault planes that bound the ore suggests strongly that these fault planes were developed before the ore was formed. There is no reason for supposing that the formation of these faults was confined to that probably very brief interval between the formation of the sulphide ores and the formation of the quartz veins; rather the development of these fault planes may be ascribed to the time of intense dynamic disturbances that resulted in the shearing and crushing of the rock, and that certainly antedated the formation of the copper deposits.

Although the places of deposition of ore are confined to broad zones or regions where the rock has been sheared, the exact outlines of the ore body formed at any place have been further limited by local variations within these main belts of dynamic disturbance. Consequently the ore bodies, which, as stated, are commonly of rather tabular shape, do not necessarily conform with the plane nor the strike along which these dynamic disturbances are expressed by extensive schistosity and shearing.

In the Bully Hill district the main ore bodies occur in steeply inclined lodes or local zones of intense shearing, which are parts of and correspond broadly in direction with the main shear zone of the district. Extension in depth in the case of these deposits is therefore a vital matter, whereas cross sections of the ore bodies at any given elevation are of small area in comparison with the flat and comparatively thin deposits west of the Sacramento. Conditions somewhat similar to those at Bully Hill probably exist in the Afterthought region, though developments there are less extensive and the relations are less evident.

West of the Sacramento, on the other hand, the main shear zone crossing the Iron Mountain and Little Backbone districts appears to comprise more complex components of extreme intensity of movement, so that the principal ore bodies that are formed in these greatly crushed places do not correspond in strike to the main direction of the zone. They are mostly rather flat lying and have been followed, up to the present time, to comparatively shallow depths below the surface. Just why the bodies of ore representing originally masses of rock most thoroughly crushed should have the shape and attitude that they possess is a matter concerning which no satisfactory evidence of direct nature has been observed. In many places the walls that bound the sides of these ore bodies are regarded as fault planes formed earlier than the ore, as previously explained. The roof and the floor, which are boundaries of greater areal importance, are probably in some places similar faults of flat attitude, but most of them are comparatively abrupt transitional boundaries between portions of the rock that are greatly brecciated and portions that are much less shattered. But why such planes and boundaries should be prevailingly of flat dip is a question to which only one answer has suggested itself—that in the arching up of the shales of the Kennett and Bragdon formations, which without doubt originally covered the alaskite porphyry mass at no very great distance above the present surface, the cooling porphyry may have been subjected to stresses approximately parallel with this gradually yielding cover of shales, and these stresses resulted in flat zones of crushing and shearing. The presence of shale in the Afterthought district is thought to have thus influenced in a small and intimate way the structure of the near-by porphyry. The Iron Mountain ore body is limited above by a capping of gossan and appears to be limited at the bottom by the convergence of two distinct walls, which are believed to be faults that antedated the formation of the ore; but the results of extensive diamond drilling in the gossan, which was derived from the original sulphide body of Iron Mountain, indicate that that original body also, like the Balaklala, Shasta King, and Mammoth ore bodies, had a comparatively flat roof and floor of alaskite porphyry. In some of the smaller deposits of ore, as, for instance, at the Golinsky mine, the flat attitude of the deposits is less evident and there is some indication of conditions more resembling those at Bully Hill, though the size of the ore bodies and the amount of development do not justify final conclusions in this regard.

Faulting since the formation of the ores does not appear to be of general importance. Faults of small throw are known to cut the Iron Mountain and Hornet ore bodies, and one or more faults separate the originally continuous Balaklala ore body into sections. There is some evidence pointing toward the idea that the Balaklala and Shasta King ore bodies were originally parts of the same great mass and have been separated by one or more faults, probably of the same system that is known to occur in the Balaklala mine. One of these faults may be approximately indicated by the line of Squaw Creek. The amount of development is not yet sufficient to settle this important question, but some light may be thrown on it by exploration work which it is understood is being done at present by the Balaklala Company on an outcropping of ore lying between the known ore bodies of the Shasta King and Balaklala mines. It is not beyond the bounds of possibility also that other faulted blocks of the original Balaklala ore body may exist to the south of those now known, though, on the other hand, such blocks that might have existed may have been removed by erosion. A transverse system of faults later than the ore is also present in the Balaklala mine.

It is not unlikely that some of the fault planes, formed before the deposition of the ores, have later been the scenes of additional movement, so that the wall rock originally adjoining the ore body has been displaced to some extent. Boundaries that are regarded as possibly of this nature occur in the Mammoth and Shasta King mines.

Bodies of some of the most massive sulphide ore, as in the Mammoth mine, are cut into small blocks of more or less regular shape by various systems of joints which are wholly confined to the ore body and which in some places fail near the walls so that the outer portion of the ore body is a hard, continuous shell of ore a foot or two in thickness. Here and there, however, joints cut even this peripheral portion, which is most apparent near the roof of the ore body. Along some of these joints within the mass of the ore slight displacement has occurred, producing faults ranging in throw up to 2 or 3 inches.

It is obvious that channel ways must have existed through which the ore-bearing solutions were carried from their source to their places of deposition. In the case of the ore bodies occurring in steeply inclined shear zones of indefinite depth, as in the Bully Hill district, it may be readily assumed that these shear zones are themselves the channels along which the ore-bearing solutions ascended. In the principal deposits of the western districts, however, no such feeding channels have yet been discovered; whether they are small and have escaped observation and recognition, whether they have in general been cut off by subsequent faulting, or whether they have not yet been revealed by development can not be stated. Exclusive of the surface outcrops, which must be considered simply as chance exposures by erosion, feeding channels from above are more certainly absent.

MINERALS AND THEIR RELATIONS.

The mineralogy of the Shasta County copper deposits is exceedingly simple. Pyrite, the ordinary sulphide of iron, is the most abundant ore mineral, and chalcopyrite, the copper-iron sulphide, is the chief one which gives to the ores their value as sources of copper. Sphalerite, or zinc blende, is also present in varying amount; on the average it possibly exceeds the chalcopyrite, but in only one place, the Donkey mine, has this mineral been found in sufficient abundance to be utilized up to the present time as a source of zinc. Other metal-bearing minerals are present only in small amount. Galena is found in small crystals and grains generally associated with the zinc sulphide, especially in the eastern districts of the region. Coatings of radially arranged fibers of iron sulphide of lighter color than pyrite and thought to be marcasite occur on pyrite in one of the Arps tunnels near Copper City. Minute black grains and needles or blades, the latter in places arranged in feathery or dendritic forms, are found surrounded by pyrite and chalcopyrite in the Bully Hill district; the appearance is suggestive of magnetite, but the grains are too small for detection without the microscope, and tests for magnetic material can not therefore be applied; furthermore, even if this mineral is magnetite, it is not certain that it was deposited with the ore—it may possibly be original magnetite of the alaskite porphyry unchanged by the ore-forming solutions, though this seems doubtful. Bornite, a copper-iron sulphide richer in copper than chalcopyrite, and chalcocite, the cuprous sulphide, are present in small amount in the ores of the eastern districts in the same manner of occurrence as that shown by the chalcopyrite, which will be referred to shortly. Diller states [a] that tetrahedrite, the copper-antimony sulphide, has been reported from the Bully Hill mine, and the presence of antimony in the ore or in the copper bullion has repeatedly been mentioned; but the "gray copper" pointed out to the writer in the Bully Hill mine proved to be ore blackened by the presence of secondary chalcocite.

[a] Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 12.

No minerals have been found which account for the presence of antimony or of the bismuth, arsenic, and selenium that have been stated to occur in the Bully Hill ores and to some extent in those of Iron Mountain. It is the belief of some that the refractory character of the ores, occasioned by their content in zinc and barite, was responsible for the idea that some of these unusual and metallurgically rebellious elements were present.

The minerals that have resulted from the alteration of the primary ore minerals above mentioned include limonite and perhaps other hydrous oxides of iron; magnetite; secondary chalcopyrite, bornite, and chalcocite; cuprite or red copper oxide; native copper; small amounts of malachite and azurite, the copper carbonates; chalcanthite, melanterite, and goslarite, the hydrous sulphates of copper, iron, and zinc, respectively; and small veinlets believed to be smithsonite (zinc carbonate). Diller reports native silver; [a] argentite (silver sulphide) was probably also present. These products of alteration will be again referred to on a later page.

The minerals that can, without qualification, be called gangue minerals consist of quartz, calcite, and barite, or heavy spar. The calcite perhaps carries manganese in places, for manganese oxide (wad) is found in the oxidized zone. Here and there it appears also to carry some iron and approach siderite in composition. Because of their common occurrence in the ore, two other minerals must be regarded as gangue minerals, namely, chlorite and sericite,[b] though both of these, as well as a part of the quartz, were not formed entirely from the minerals carried in the ore-bearing solutions, but were produced by the interaction of these solutions and mineral components of the alaskite porphyry. The chlorite was derived from the basic silicate minerals of the alaskite porphyry, and the sericite was formed from the feldspars of the porphyry chiefly through the solution of soda and the deposition of potash in place of it. Bodies of gypsum, the hydrated sulphate of calcium, are found associated with pyrite and a little chalcopyrite in deep levels of the Bully Hill and Rising Star mines. Microscopic examination of specimens of this gypsum shows that it contains cores of anhydrite, the anhydrous calcium sulphate. Anhydrite was undoubtedly the primary mineral in this region wherever gypsum has been found, and was probably formed under conditions similar to those which permitted the development of the similarly constituted barium sulphate (barite), which is present in much greater quantity. Extremely minute shreds of material found in the ore of many deposits are believed to represent one and possibly two other minerals, though as yet their identity has not been ascertained.

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[a] Loc. cit.

[b] Possibly paragonite in part. See footnote on p. 88.

As has previously been stated, the replacement of crushed country rock to form ore did not progress to the same degree everywhere. At few localities has replacement of the country rock, by ore and gangue minerals wholly supplied by the ore-bearing solutions, been complete. The most complete replacement of important masses of the rock appears to have occurred in the Mammoth and Iron Mountain ore bodies, and much of the ore of those mines is practically solid sulphide with very little quartz and, in the Mammoth, at least, an occasional grain of barite. Locally, in ore bodies of the Bully Hill and Afterthought mines also, replacement has been complete. As a rule the ore consists rarely of sulphide minerals only, but contains more or less abundantly calcite, barite, and less commonly quartz.

The characteristic and typical ore of the region, such as might be encountered in any chance specimen, is a product of only partial replacement of the country rock by the materials derived from the ore-bearing solutions. In such ore quartz is generally more abundant than in the ore that represents complete replacement, and with the quartz are associated more or less sericite and chlorite. The quartz, which appears to be about the youngest constituent of the ore, commonly surrounds the grains or crystalline clusters of sulphide minerals as a mesh work of veinlets which for the most part are much narrower than the diameter of the sulphide grains. In some places the quartz of these interstitial streaks consists of grains showing radial extinction under crossed nicols and corresponding in all respects with the quartz often met with in ordinary veins. As a rule, however, the quartz has a shredded or coarsely fibrous appearance, the fibers extending at right angles to the face of the adjoining sulphide grain and very commonly showing a curving or twisting similar to that which would result if it had been crushed since crystallization. In some places, notably in a tunnel of the Reno group, in the southwestern part of the Bully Hill district, originally solid sulphide has been finely shattered and the spaces between the minute angular fragments have been filled with quartz of this nature. In general the shredded or fibrous appearance is probably not due to pressure and crushing, but to the influence of sericite which the quartz replaced. Quartz is most plentiful at the Balaklala[a] and Shasta King mines, but this is due to the fact that parts of the rock have resisted impregnation by sulphide minerals though allowing the deposition of quartz; ore of this nature has the appearance of a breccia in which the sulphides, as matrix, include numerous small fragments of much silicified country rock. Intergrown with this

[a] The average content of total silica, free and combined, for the Balaklala ore body is stated to be between 15 and 20 per cent.

shredded quartz are more or less abundant foils and shreds of the sericitic variety of muscovite mica, also similar particles of chlorite, though this last-named mineral occurs locally in more distinct blades or in vermicular aggregates of minute plates. Calcite also occurs with the quartz, both as elongated grains between the quartz fibers and in more compact forms surrounded by these fibers. Where particularly abundant it also forms veinlets surrounding the sulphide minerals like the mesh work of quartz.

Barite may be regarded as the characteristic mineral in the districts east of Sacramento River; quartz is most abundant in the western districts. Barite, however, is not important in all the eastern deposits, occurring in the Rising Star mine, in the Bully Hill district, for example, so far as observed, only as a few exceedingly small crystals. Moreover, barite is not absent in the western districts. It occurs in good-sized grains in the gossan directly above the Mammoth ore body and has been recognized in much smaller particles in the sulphide ore of both the Mammoth and Golinsky mines, and it is reported to be present in grains of sufficiently large size to be detected in hand specimens of the ore from the Golinsky mine. It is thought to be present also in extremely small grains in some of the Iron Mountain and perhaps other ore bodies, but it could not be identified with certainty under the microscope, and chemical investigation of these ores is not yet completed. According to Diller, however, barium occurs in the wall rock not far from the Iron Mountain ore body; it seems probable that it was deposited there by the ore-bearing solutions,[a] and it is therefore not unlikely that barite is present also in the ore. Similarly, quartz, though especially characteristic of the ore deposits of the western districts, is found in some amount in those of the Bully Hill and Afterthought districts and is particularly common in the ore of the Rising Star mine. Quartz and barite, therefore, may be regarded in a sense as complementary, one being important where the other is absent or rare, and vice versa. Where most abundant the barite is in more or less regular prisms which are of better crystalline form than the surrounding minerals and therefore doubtless crystallized slightly earlier. It is also present, however, sometimes in the same specimen, as aggregations of small irregular grains that exhibit the same meshlike relation to the sulphide minerals that quartz commonly does, and in some places it is intergrown with the shredded quartz in the same manner as the sericite, chlorite, and calcite. Calcite is rather more abundant in the ore that is richer in barite, and is particularly noteworthy in the ore of the Copper City and Afterthought mines, in both of which the ore bodies are situated close to large masses of shale or tuff. The gypsum, so far as its presence has been recognized, seems to occur in large bunches or masses

[a] See footnote, p. 108.

which commonly have a banded structure, due to the inclusion of thin parallel films of sericitic and chloritic material. Though these bunches contain sulphides, they are not directly adjacent to commercial ore; ore occurs near by, however, in the same shattered zone in which they are situated. This material has been found at least as deep as the 870-foot level in the Bully Hill mine and nearly as deep in the Rising Star mine. It contains countless disseminated crystals and grains of pyrite and can not be regarded as the result of leaching from overlying calcareous material. The presence in it of anhydrite establishes the secondary nature of the gypsum and indicates that the calcium sulphate substance was introduced by the ore-bearing solutions. From the readiness with which plaster of Paris, which is anhydrous calcium sulphate, equivalent to anhydrite, becomes hydrated and assumes the same composition as gypsum, it may be inferred that the anhydrite has been preserved only in the most impervious parts of its original mass. The remnants of anhydrite show that the mass was composed of small crystalline grains which possessed a structure similar to that of fine-grained marble. The only other known occurrence, in this country at least, of anhydrite in connection with ore deposits is in the Frisco district of Utah,[a] where it is present in copper ore along with its hydration product, gypsum, and with barite, but in a very different mineral association from that of the Shasta County region.[b]

Among the ore minerals pyrite was the first to crystallize in most places, and where it was not so abundant that various crystalline particles interfered with each other in their growth, the mineral is present in cubes and less commonly in pentagonal dodecahedrons (pyritohedrons) of more or less perfect crystalline outline. Where it constitutes a large percentage of the ore, however, as is generally the case, the develoment of crystalline faces has for the most part been prevented, but small irregular grains, of individual internal crystalline structure, adjoin along irregular boundaries. The material that is thought possibly to be magnetite is surrounded by the pyrite and is therefore of older formation. In rare instances small grains of chalcopyrite, bornite, chalcocite, and sphalerite are inclosed in the pyrite individuals. The zinc sulphide in such places commonly has crystalline boundaries.

Zinc blende is, on the whole, of later formation than the pyrite, spreading around the grains of the iron sulphide in many places along certain crude bands which appear in the hand specimen as narrow dark streaks and give much of the zincky ore a characteristic banded

[a] Lindgren, Waldemar, Science, new ser., vol. 28, 1908, p. 933.

[b] The ore body of the Cactus mine in the Frisco district of Utah is a mass of much-shattered monzonite impregnated and replaced by pyrite, chalcopyrite, galena, sphalerite, tetrahedrite, specularite, quartz, calcite, siderite, tourmaline, barite, anhydrite, and, of secondary derivation, gypsum. This association of minerals indicates that they were formed under conditions of high temperature and pressure.

appearance. In a few places it can be seen that these bands correspond to the original direction of shearing in the country rock now replaced. Except where inclosed within the pyrite the zinc sulphide consists of aggregates of tiny crystalline grains and no definite crystal faces have been developed. The sparing quantity of lead sulphide that has been formed possesses a more perfect crystalline development than the zinc blende, by which it is inclosed and which probably was deposited immediately after its formation.

Chalcopyrite is in general the youngest of the important metalliferous minerals, for it occurs in the ore as indefinite and irregular branching veinlets that form a network around and in cracks of the other sulphide minerals. Where zinc blende is present the chalcopyrite seems to prefer association with that mineral rather than with the pyrite, and it may be noted that in the mines carrying the lowest grade of copper ore zinc is less abundant than elsewhere. The chalcopyrite also shows affinity for quartz or barite, and where either of these two gangue minerals forms a network among the pyritic material the chalcopyrite is most likely to occur along the boundaries of these irregular veinlets as borders to the pyrite grains.

In the western districts quartz veins that normally carry a very small percentage of chalcopyrite cut through the ore here and there. In many places on reaching the ore body they split and branch and ultimately fade out. It is generally true that they hold much larger proportions of chalcopyrite where they are inclosed within the sulphide ore bodies than where they are bounded by the country rock, and in extreme cases they become veins of practically solid chalcopyrite in which the normal amount of quartz has dwindled to a few included prismatic grains. In many places along but definitely outside the boundaries of these quartz-chalcopyrite veins the ore is richer in chalcopyrite than elsewhere. Where these veins fade out they send out many minute stringer-like offshoots into the ore. These tiny quartz stringers appear to merge gradually into the shredded quartz normally present in the sulphide ore. All along these microscopic branches of the definite quartz veins chalcopyrite is deposited in greater amount than usual.

Bornite is only rarely present in large amount in the primary ore; it occurs most plentifully in the Bully Hill and Afterthought mines and is present in very small amount in some of the other deposits. It is very commonly associated intimately with copper glance, or chalcocite, and these two together apparently take the place of chalcopyrite wherever they occur, forming the same kind of irregular network through and around the other sulphides. These two richer copper sulphides are in some instances intergrown with the chalcopyrite, in places inclosing it and in places being inclosed by it. These two minerals were found in the deepest workings of the Afterthought mine, at a depth of about 600 feet, and in the deepest workings of the Bully Hill mine, at 970 feet, as well as at higher levels. In places they are intergrown with and even entirely surrounded by barite, and there is no reason whatever to consider them as other than primary constituents of the ore. Both bornite and chalcocite, as well as chalcopyrite, however, are also formed in the upper portions of some of the ore bodies by the process of secondary enrichment, but almost all such occurrences can be readily distinguished from those in which the minerals are of primary origin.

The statement made at the beginning of this section, that chalcopyrite is the mineral which generally gives to the ores their value as sources of copper, is probably, though not certainly, strictly true. Certain thin sections of ore from small specimens, assays of which show the presence of copper up to more than 2 per cent, appear under the microscope to contain no recognizable chalcopyrite, the only sulphide that can be identified being pyrite. Whether the copper contained in such ore exists as chalcopyrite, in such small grains and so intimately mingled with the pyrite that it escapes detection, or whether the pyrite contains, as an essential part of its composition, some copper, can not now be stated, though the former view seems the more reasonable, especially in view of the fact that this copper-bearing pyrite has an appearance somewhat different from that of the pyrite of the ore which is nearly barren of copper, the thin section being of slightly more yellowish color and of rougher surface on the ground faces. It is probable that the pyrite in all the ore that is commercially valuable carries copper in this way from a very slight percentage up to 2 per cent or more. The gold and silver values contained in the ore appear to be carried within the sulphide minerals, for no definite gold or silver minerals of primary origin have been found. Some of the zincky ore carries more than the normal quantity of silver. Both gold and silver are on the whole more plentiful in the ore rich in barite, but the cause of this relation is not known.

Most of the replaced country rock that is sufficiently rich in sulphide minerals to appear to be composed largely of such minerals carries sufficient metal values to make its extraction possible. Exceptions to this rule occur, however, in some places, and of course the exceptions are influenced by the lowest limit of value at which the ore can be profitably handled. Some of the fairly massive sulphide that is too low in copper to be extracted owes this condition to the fact that the copper values have been to some extent removed by leaching; where that is the case the sulphide is likely to be crumbly and may even become merely pyritic sand. Material of this kind is found in places in the Mammoth, Shasta King, and Iron Mountain ore bodies, and perhaps elsewhere. Conversely, little material not composed in large part of sulphides carries enough copper to be workable, though locally in the Bully Hill and Afterthought districts precious metals make possible the mining of ore that resembles the "waste" of other camps. The upper limit of richness in copper in the primary ore is practically fixed by the theoretical copper content of chalcopyrite, which is 34.5 per cent, though in the Afterthought mine portions of stopes are so rich in bornite and chalcocite that this percentage is locally exceeded. A few masses of pyritic ore of homogeneous appearance yield assays as high as 30 per cent of copper. Rich ore of this kind has been found in places in the Mammoth, Iron Mountain, and Bully Hill mines, but the great bulk of the ore is, of course, of much lower grade. Exclusive of the enrichment that has taken place in the upper portions of some of the ore bodies, which is due to additions of cupriferous material from the oxidized zone above, there appears to be little uniformity in the distribution of richer portions of the ore. In the Bully Hill mine there seems to be a tendency for the best ore to be found near the middle of the ore body, though in places the borders of the ore body are rich in barite and correspondingly high in copper as well as in gold. In the Mammoth and Shasta King mines probably the richest general portion of the ore bodies lies near the bottom wall or floor. Whether or not such conditions exist in the other mines is not known. At the Mammoth the harder shell that is found especially at the top of the ore body is said to be a little richer than the ore just inside of it. It may be that the shell itself and its higher copper content are the result of cementation and enrichment by solutions that have slowly seeped down the slanting roof of the ore body from positions nearer the surface, but no direct evidence of this has been observed.

ALTERATION.

Some of the ore bodies, like the main mass of the Hornet mine, do not reach the surface; and others, like the Balaklala, Shasta King, and Mammoth, have comparatively small outcrops of what was originally actual ore. At Bully Hill the steeply inclined ore body extended to the surface, and at Iron Mountain there is an enormous outcrop representing an original body of ore far greater in size than that which has been available for extraction. The rock surrounding the ore bodies is comparatively impervious to atmospheric waters and has well protected from oxidation and solution such portions of the ore bodies as lie below it. The exposed portions of the ore bodies, however, have been much altered, and at the Bully Hill and the Iron Mountain mines this alteration has extended to considerable depths. The most important result has, of course, been the production of an iron hat or gossan, consisting chiefly of limonite, some magnetite, and perhaps other ferruginous oxides. Much of the iron contained in the pyrite and chalcopyrite has thus been oxidized and rendered comparatively stable to atmospheric conditions. In the process of this oxidation the copper has been dissolved and removed from its original position. A large part of the copper thus taken into solution has undoubtedly escaped or has been precipitated in meager amounts through wide stretches of rock, but in some places an important portion of the copper derived from the oxidized ore has found its way downward below the zone of active oxidation into the underlying less altered ore and has there been precipitated upon and by the influence of the primary sulphides, according to the now well-known process of secondary sulphide enrichment. In this way secondary chalcocite, bornite, and chalcopyrite have been formed. These minerals on oxidation have produced native copper, cuprite, and the carbonates in sparing amounts. At Bully Hill and Iron Mountain these enriched zones of oxide and secondary sulphide material were of importance, though in both camps the silver values, which had likewise been concentrated with the copper from the overlying oxidized masses, were chiefly sought at the time these enriched zones were worked, and a large part of the copper therefore undoubtedly failed to be recovered. Enrichment in much smaller amount has taken place near the outcrops of the Mammoth, Shasta King, Balaklala, and Afterthought ore bodies.

The rock, partly impregnated by sulphides, that surrounds the ore bodies and occurs at other places has at the surface also undergone alteration; the sericite has been converted into kaolin and the contained pyrite has been oxidized to limonite, which has been partly absorbed in the kaolin and has stained the rock with various colors of red, yellow, or brown. Such altered wall rock, deeply stained with iron oxide but containing far less of that constituent than the true gossan derived from heavy sulphide material, is also given the name gossan in the Shasta County region, but, as pointed out by Hausmann,[a] such a designation is erroneous and, it may be added, has led to misconceptions regarding the relations of sulphide ore bodies to oxidized outcrops.

GENESIS.

There can be no doubt that the Shasta County copper deposits, like most ore deposits elsewhere, have been formed through the agency of aqueous solutions, either liquid or gaseous, which held dissolved in them part or all of the material now comprising the ore. An explanation of the origin of these ore bodies must give information as to the chemical character of these solutions, their source, and the manner in which the materials that they furnished were precipitated from them.

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[a] Bull. California State Min. Bur. No. 50, p. 64.

The simple mineralogy of the Shasta County ores—the general absence of minerals of critical or diagnostic character—makes it difficult to draw conclusions concerning some of these questions, and the incomplete state of chemical and microscopical investigation of the material collected from this region makes any conclusions that might now be presented still more uncertain. Some views, however, seem to be fairly well justified by the studies thus far accomplished and may here be recorded. The unfailing connection of the copper deposits with the alaskite porphyry has already been emphasized, and the view regarding differentiation of the magma which is believed to have yielded the alaskite porphyry, the quartz diorite, and the basic dikes has been outlined under the heading "General geology." It is believed, moreover, that the quartz veins which carry chalcopyrite and in places gold and the copper ore bodies and the similar materials which impregnate both the surrounding walls and the general country rock have also been derived as final stages of differentiation from the same magma. The geographic and time relations of the ore and the alaskite porphyry are in accord with such a view.[a] The ideas held regarding this hypothesis may be further stated as follows: The shattering and shearing of the alaskite porphyry took place directly after the solidification of that rock. Immediately afterward came the intrusion of the quartz diorite and, finally, that of the basic dikes, which represent the latest rock product of the magma and which in some places, as in the Bully Hill mine, have been intruded along shear zones already developed in the alaskite porphyry. As these various rocks separated out from the magma, a progressive concentration of water and of various other elements resulted, and after the intrusion of the last rock product, the dikes, there still remained in the magma reservoir water-rich material or solutions that might be regarded as the mother liquor from which the various rocks had crystallized. These solutions are believed to have been rich in the elements that would form quartz, iron and copper sulphides, barite, calcite, etc., and because of the fact that sericite has been formed abundantly from the original sodic feldspar of the alaskite porphyry, it is believed that potassium, probably in the form of carbonate, was present in important amount.

[a] Two analyses of the alaskite porphyry, from Bully Hill and from Iron Mountain, published by Diller, show the presence of small quantities of barium in the material analyzed, and to account for its presence he explains that the feldspar of the rock contains this element. If the barium were actually an original constituent of the rock, its appearance in the ore deposits also would constitute the strongest available evidence of the relation of the ore solutions to the porphyry magma (the theory of lateral secretion being disregarded as of no application in this case at least). However, the fact that both of Diller's specimens were obtained near the ore bodies, and so might have received from the ore-bearing solutions small amounts of barite, and the added fact that, though searched for especially, no barium was found by the Survey chemists in any of the freshest specimens of alaskite porphyry collected during the recent investigation (one of these specimens—see analysis, p. 83—was obtained near the Bully Hill mine) make it appear unlikely that barium was present in appreciable quantity in the alaskite porphyry, which was the first product of differentiation from the magma.

Shortly after the intrusion of the dikes these solutions were probably forced upward from their source through such channels as they were able to discover, and these channels proved to be places of shearing in the alaskite porphyry. These solutions, which in their heated condition were probably vigorous chemical reagents, attacked the porphyry, especially where it was most crushed. The rock was more or less replaced by the elements carried in solution, and the deposition of the ores and the widespread alteration of the country rock were in this way accomplished. The silica or quartz of the rock was probably partly dissolved by the alkaline (potassium) carbonate of the solution and such of the feldspar and bisilicates as were not completely replaced by minerals of the ore bodies were converted mainly into sericite and chlorite. The quartz veins carrying chalcopyrite and gold are believed to have closely followed the intrusion of the basic dikes. One possible evidence that may be cited in favor of this belief is the fact that both dikes and veins are commonly found occupying the same fractures, each in turn having found these fractures to be places of greatest weakness. The formation of these quartz veins is believed to have so closely followed the development of the great copper ore bodies that the minerals of these great sulphide masses were scarcely precipitated when the quartz veins penetrated them. The manner in which the quartz veins finger and fade out into the sulphide masses and the way in which the quartz veins and the sulphide ores have mutually influenced each other in the abnormal deposition of chalcopyrite in and near the veins seem to point to such a conclusion. In fact, it is believed that the quartz and chalcopyrite of the distinct quartz veins and the quartz and chalcopyrite which were the latest minerals to be formed in the copper ore are practically identical in character, source, and age. Whether or not the definite quartz veins carrying chalcopyrite and gold are to be regarded as most intimately related to and really a phase of the irregular sulphide-bearing quartz masses or veins that constitute a special type of the pegmatitic dikes connected with the quartz diorite is a matter not yet decided. Consideration of all the evidence seems possibly to favor the idea that such immediate relationship does not exist, but that the pegmatitic quartz was of somewhat earlier formation. In any event, these pegmatites, though not abundant, are of interest and significance as indicating that these water-rich portions or products of the magma carried sulphide minerals and high silica, just as did the ore-bearing solutions.

There is in this region little evidence of pneumatolysis—that is, the action of mineralizing solutions in gaseous form. It is probable that most or all of the ore-forming materials were carried in the liquid state.

If the foregoing views of genesis are correct, every important circumstance connected with the origin of the primary copper ores is definitely related to one event, namely, the intrusion of the alaskite porphyry and its closely subsequent relatives. The inclosing rock, the channel ways that permitted ingress of the ore-bearing solutions, the comminution of the rock that made it easily attacked by these solutions, and the solutions themselves that furnished the material of the ore and brought about the alteration of the surrounding walls are thus but component elements of a single broad geologic phenomenon—intrusion. The hypothesis that the ore deposits are the work of descending, meteoric waters which derived ore-forming materials from the rocks overlying and adjoining the places where the ore bodies are situated is not believed to have application in the Shasta County region. It is believed that at the time the ores were deposited the alaskite porphyry was everywhere covered with a blanket of shales which would tend to prevent the direct and free circulation of surface waters; if they reached the region of the ore bodies at all, they must have traveled by a roundabout route and to considerable depths. Furthermore, it is believed that the ores were formed so soon after the consolidation of the rock that it was probably still at comparatively high temperature, a condition in which surface waters in large amount could probably not have penetrated into it.

Evidence as to the depth at which the ore bodies now known were deposited below the surface of the country existing at that time is rather meager. From mineralogical, structural, and physiographic evidence, however, it may safely be concluded that all the portions of ore bodies now known were at the time of their formation so deeply buried that they had no direct relation to the surface then existing. On the other hand, the fine-grained texture of most of the porphyry and the generally small extent to which the surrounding sediments have been metamorphosed at its contact, as well as the mineralogical character of the ores themselves, make it seem probable that the thickness of rock overlying the ore bodies at the time of their formation was not extremely great; 5,000 to 6,000 feet is believed to exceed the initial depth of most of them below the surface. In the classification with respect to physical conditions existing at the time of formation,[a] these Shasta County deposits would correspond to veins of the middle zone. In age they may be ascribed to the interval, characterized in the western Cordilleran region by intense eruptive activity, that marked the close of the Jurassic and the beginning of the Cretaceous. They thus belong in the third or late Mesozoic metallogenetic epoch as established by Lindgren.[b]

[a] Lindgren, Waldemar, Econ. Geology, vol. 2, 1907, pp. 105-127.
[b] Econ. Geology, vol. 4, 1909, pp. 415-416, 419.

Inasmuch as the present topography of the region is known to be decidedly different from that existing when the ores were formed, the fact that many of the important ore bodies of the region are flat and not far below the present much diversified surface is probably without scientific significance. There is no reason to expect, therefore, that other ore bodies than those now known are not present at greater depth, though such ore bodies do not, of course, necessarily exist, and the chances of finding them are much lessened by their greater depth and their absence of surface indications. It seems probable that of all the ore bodies ultimately to be found in the region those already known are among the best, though important new bodies, or extensions of known bodies in the same general zone of shearing, may very well be discovered. It is not impossible that prospecting at points distant from known deposits, where the rock shows the greatest amount of shearing and alteration, may be rewarded by the finding of important masses of ore.

GEOLOGY OF THE COPPER DEPOSITS NEAR MONTPELIER, BEAR LAKE COUNTY, IDAHO.

By Hoyt S. Gale.

INTRODUCTION.

The copper deposits in the vicinity of Montpelier, Idaho, in the "Red Beds" of supposed Triassic age, appear to be entirely analogous to deposits of the same geologic age noted elsewhere throughout the Rocky Mountain region, and even in other parts of the world.[a]

Copper carbonate and some sulphide minerals, found in sedimentary rocks, where they are characteristically associated with the carbonized fragments of plant remains, and apparently without relation to igneous rocks, have been the subject of some interest in the Montpelier district for a number of years. A moderate amount of prospecting has been done on these deposits, but has not yet proved their character or value below the surface. The territory in which most of the prospecting has been done lies in a narrow strip represented on the accompanying map (fig. 6), extending almost due north and south through Tps. 11, 12, and 13 S., R. 45 E. of the Boise meridian, Idaho. The outcrop of the rock formation including the copper-bearing beds is readily traceable much beyond the area described here, and these rocks are also easily identified in neighboring mountain ranges, but from present information it can not be stated just how far the copper minerals may be traced or where they will be discovered again.

[a] Emmons, S. F., Copper in the red beds of the Colorado Plateau region: Bull. U. S. Geol. Survey No. 260, 1905, pp. 221-232.

Lindgren, Waldemar, Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 170-174.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910 (in press).

GEOLOGY OF THE COPPER-BEARING ROCKS.

The copper minerals found in this district occur in rocks of probable Triassic age. So far as known they are confined with notable persistence to a well-defined horizon or stratum in the formation

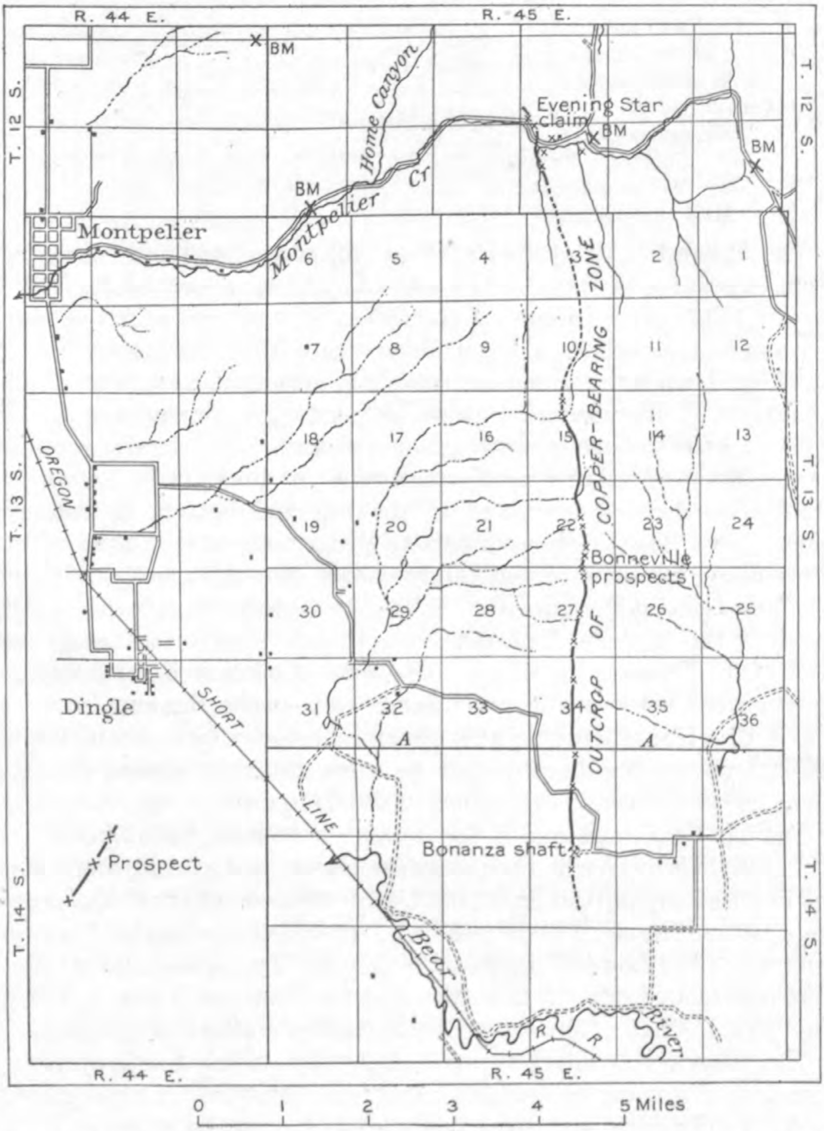

FIGURE 6.—Map showing distribution of copper-bearing rocks near Montpelier, Idaho. *A–A*, Line of section (fig. 7).

that has been named the Ankareh shale. The relation of the Ankareh shale to overlying and underlying geologic formations is indicated in the table following.

Geologic formations in Montpelier district, Idaho.

Jurassic:
- Twin Creek limestone.

Jurassic or Triassic:
- Nugget sandstone.

Triassic or Carboniferous:
- Ankareh shale.
- Thaynes limestone.
- Woodside shale.

(Ankareh shale, Thaynes limestone, Woodside shale: Permian (?); the "Permo-Carboniferous" of the Fortieth Parallel Survey.)

Carboniferous:
- Pennsylvanian—
  - Park City formation.
  - Weber quartzite.
- Mississippian.

The Ankareh shale of the Park City section was originally described from exposures in Big Cottonwood Canyon southeast of Salt Lake City, Utah.[a] This formation consists chiefly of clay shale of deep maroon and chocolate colors, massive where fresh, though commonly breaking down into thinner-bedded shaly material on exposure to the weather. It includes also some pale-greenish clayey and sandy strata, locally in beds of mottled green and maroon. It also contains harder layers of red or greenish sandstone and limy strata, and in the Montpelier district is defined at the top and bottom by massive limestones. The overlying limestone distinguishes the Ankareh from the massive sandstones and sandy shales of the Nugget sandstone. The limestone at the base of this "red-bed" formation is the uppermost of the massive limestone strata that constitute the greater part of the Thaynes limestone. The total thickness of the Ankareh, as measured between the two limestones near the Bonanza shaft, is about 670 feet, including the upper limestones but not including massive underlying limestone strata, more naturally classed with the main body of massive limestones in the Thaynes.

The Thaynes limestone is the formation occurring next below the Ankareh shale in a normal sequence and was named from its occurrence in Thaynes Canyon, near Park City, Utah. It includes the "*Meekoceras* beds" of southeastern Idaho, which have yielded a fauna that has been referred to the Lower Triassic by Hyatt and Smith and others.[b]

It is evident from recent works that the Thaynes is also a part of the "Permo-Carboniferous" of the Fortieth Parallel Survey.

The Thaynes is characterized chiefly by massive ledge-forming limestones, in many places abundantly fossiliferous. It also includes many shaly layers and to a minor extent some brown-weathering calcareous sandstones that grade into the limestone. The limestones contain a considerable percentage of clay or sand, so that on weathering they assume a sandy or muddy aspect which makes

[a] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434–458.

[b] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

many of them difficult to distinguish from sandstone except on broken surfaces. The thickness of the Thaynes limestone is about 2,000 feet, as measured in Raymond Canyon.

The Woodside shale next underlies the Thaynes limestone. It also received its name from the Park City mining district. In some places the Woodside is composed of dark-crimson shales which appear to form a fairly distinct member of the section; in others the bright-red colors are either absent or are concealed by the débris of adjacent harder strata. Red beds do not constitute the entire body of the Woodside, as the basal beds of that formation are rather uniformly composed of shaly or platy brown or rusty and muddy weathering limestone, somewhat similar to some of the Thaynes limestone beds. The base of the formation is marked by a prominent cherty limestone ledge, which is a part of the next underlying formation. The thickness of the Woodside shale is about 1,000 to 1,200 feet.

The Nugget sandstone, overlying the Ankareh shale and the copper-bearing strata, is composed chiefly of massive sandstone. It also includes intervals of sandy shale, which are, however, generally obscured at their outcrops by the talus of the harder ledges. The sandstone is at places, or even over considerable areas, vitrified to quartzite. On account of its resistance to erosion it usually forms high ridges or elevated plateau lands, according to the attitude of its beds. A most distinguishing feature of the formation is in general the massive red sandstone, in places marked by cross-bedding. An upper zone of several hundred feet is locally distinguished as a massive white sandstone, and at a number of localities, notably in the Sublette Range in Wyoming, a prominent ledge-forming white sandstone with conglomerate also occurs a few hundred feet above the base of the Nugget. The total thickness of the Nugget sandstone is about 1,900 feet, as measured in Raymond Canyon, in the Sublette Range.

Although in the normal stratigraphic succession the Nugget sandstone overlies the Ankareh shale, that order is reversed by the geologic structure at the locality of the copper deposits. The higher hills bordering the east side of the Bear River valley southeast of Montpelier, or between Montpelier Canyon and Dingle, represent an overturned anticline on whose crest or axis the massive limestones of the Thaynes are brought to the surface. Thus, while the copper-bearing rocks dip to the west and apparently pass under the massive limestones of the Thaynes, the whole section is, in fact, upside down, and these rocks probably become vertical and pass into an eastward dip in depth, from which they are continuous, merging with the general structures east of this area. The accompanying diagram (fig. 7) explains the relation of these beds along an east-west line, shown on the general map (fig. 6).

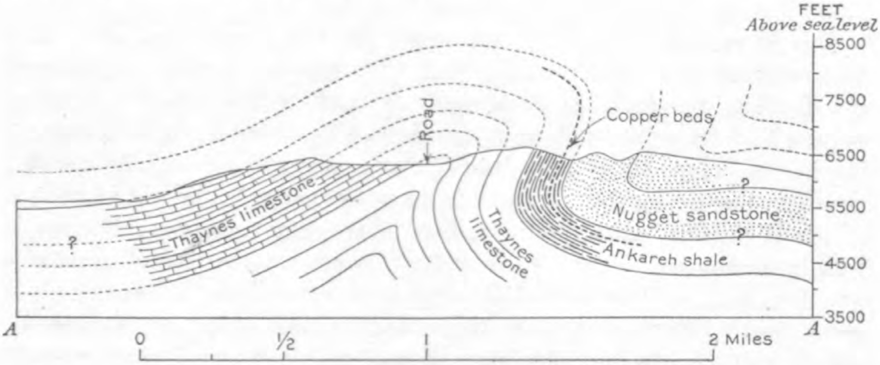

FIGURE 7.—Section along the township line on the south side of T. 13 S., R. 45 E., Idaho, showing the relations of the copper-bearing rocks.

OCCURRENCE OF THE COPPER.

Copper carbonate stains are very persistently associated with the beds at a particular stratigraphic horizon in the Ankareh shale. This horizon is about 110 feet stratigraphically below an upper limestone stratum, or 170 feet below the uppermost limestone recognized between the Ankareh and Nugget formations in the Montpelier section. The rocks at this horizon are underlain by maroon and chocolate or mottled green and red shales. On account of the overturned geologic structure of the region, the upper beds dip under those which would underlie them in the normal stratigraphic sequence, as shown by the cross section (fig. 7).

Throughout the greater part of the district examined the occurrence of copper minerals seems to be confined very constantly to approximately the same stratigraphic horizon, the only exceptions noted being those on the Bonneville claim. The section of the copper-bearing strata represented in figure 8 is apparently characteristic of this horizon, although details were found to vary as the horizon was traced along the outcrop.

As shown at the surface, the copper stains consist chiefly of the green mineral malachite and to a lesser extent of the blue azurite. These minerals occur in joints along the bedding of both the massive, usually somewhat calcareous, sandstone and in the more shaly rocks. There is no well-defined mineral streak and these oxidized minerals are, of course, secondary.

At one place where the development has been carried down on the mineralized zone to a depth of 100 feet or more the sulphide minerals chalcocite and covellite have been found in evident replacement of the woody fibers of fossil plants, roots, or tree stems. Some of the prospects are described as found at the time of examination (October, 1909).

DEVELOPMENTS AND PROSPECTING.

The principal development is on the Bonanza claim, in sec. 10, T. 14 S., R. 45 E. Here a shaft has been sunk to a reported depth of 350 feet. The mining equipment was idle when visited in October, 1909, but was in good condition. This property is said to belong to the Bonanza Mining Company, of Montpelier, organized in December, 1908.

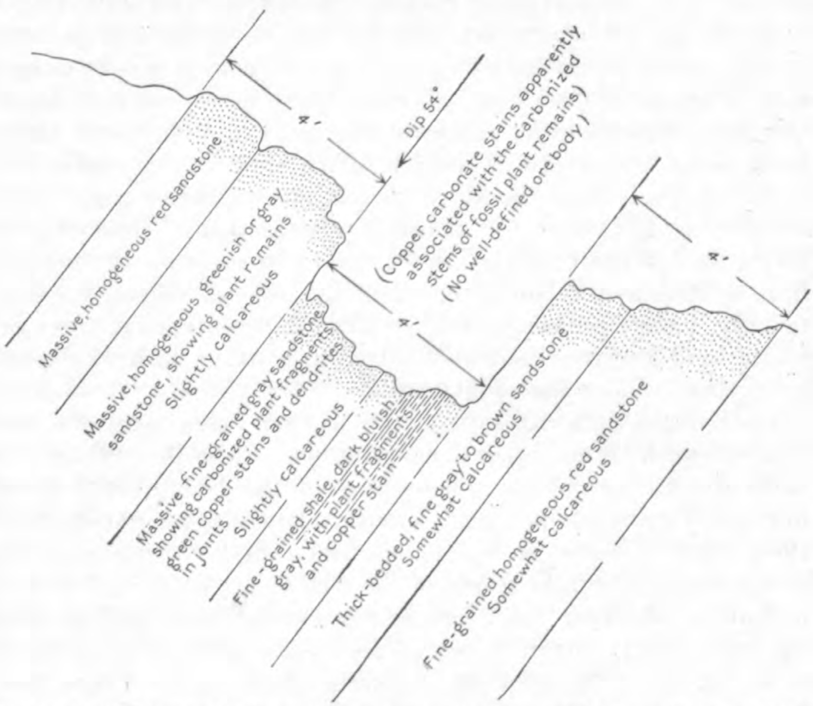

FIGURE 8.—Section of copper-bearing rocks at prospect south of Bonanza shaft, near Montpelier, Idaho.

No ore has yet been taken from the Bonanza shaft. The outcrop of the ore-bearing zone is opened by a small prospect about 130 feet east of the shaft house, where the dip is 50° W. If this dip is constant in depth, the ore-bearing beds should intersect the shaft at much less than the present depth, but no record is available, either of ore or of change in the attitude of the strata, which might explain a failure to encounter the ore. The shaft was largely filled with water and was inaccessible when the property was visited by the author.

The showing of the mineralized zone near the Bonanza shaft has already been described. (See fig. 8.)

A shaft or incline of the old Montpelier Mining Company (now incorporated in the Bonanza Mining Company) is situated on the top of the ridge about one-fourth mile south of the Bonanza shaft. The development here consists of an incline 50 feet in depth, following the copper-stained strata on the dip of the beds. The strike of the rocks is N. 10° W. and the dip 66° W. The ore at the surface is evidently of the same stratigraphic horizon as that shown near the Bonanza shaft, but occurs in brecciated zones locally more completely saturated with the carbonate minerals. These are deposited, as already noted, in joints, fractures, and bedding planes of the country rock. The mineralization is clearly not confined to any particular bedding plane or stratum, but is distributed in a very irregular way through 5 feet or more of clayey and sandy rock included between strata of massive, even-bedded red sandstones. At the bottom of the 50-foot incline, which pitches somewhat toward the north, a level has been cut to meet a timbered shaft beyond, said to have been sunk to a depth of 200 feet. Several sacks of selected ore, said to be from the 100-foot level, lie at the mouth of the pit. This ore contains much that is evidently fossil wood, in which the carbonaceous material has been replaced by chalcocite. A polished cross section of this ore proves under the low power of the microscope to be made up of rounded or fibrous masses of chalcocite; an indigo-blue iridescent mineral of metallic luster, probably covellite formed by alteration from chalcocite; and seams or veins of malachite, cutting both of the other minerals as well as the country rock.

The rocks to the south appear, from a general view across the ridges, to continue with much the same structure to the Bear River valley and beyond. In tracing the outcrop of the beds at this horizon northward from this point numerous shallow pits are noted, most of them showing more or less of copper stain, although this rarely occurs on the natural outcrop of the strata.

Another claim on which considerable work has been done is that known as the Bonneville, located near the middle of the north side of sec. 27, T. 13 S., R. 45 E., formerly owned by the Claire Mining Company. Near the head of a gulch on this property are several prospects, a shaft, and two tunnels of considerable depth. The strike here is N. 27° E. and the dip 55° W. The principal ore-bearing stratum is a light-colored calcareous sandstone, which is very hard. Ore appears to occur at more than one horizon here, a feature that was not noted elsewhere. Two tunnels run in on the north side of the gulch, opening up beds at separate horizons. The eastern of these is the main tunnel. The stratigraphic interval between the two is 60 feet.

The main tunnel has been driven to a depth of about 200 feet; from it a crosscut has been opened to the northwest, and a stope and incline have been driven on several lenticular and mineralized streaks. The mineralized beds are at least four in number within a stratigraphic thickness of 10 or 15 feet. The copper minerals are found in thin foliated shaly lenses, containing seams of black carbonaceous material, reported to constitute the richest ore. This is locally referred to as "black" copper ore, but some specimens tested showed the black substance to be largely, if not wholly, carbonaceous matter upon which the copper carbonate minerals are deposited. Surrounding such lenses of more concentrated mineralization are zones in the sandstone impregnated with the green and blue carbonates, but none of these form continuous ore bodies, nor are they well defined.

The western tunnel on the Bonneville claim, about 120 feet somewhat south of west of the main entry, was driven to follow an iron-stained ledge apparently accompanied by a smaller indication of copper minerals. The mineral here is associated with a light-colored calcareous sandstone, included in dark-maroon shale, resembling the typical occurrences noted farther south. There is relatively little copper-stained rock on the dump of this entry, which shows, however, some iron-stained sandstone.

About one-fourth of a mile north of the Bonneville tunnels and shaft, near the top of the ridge, is an old incline shaft showing copper-stained rock in striking exposure. The copper minerals are exhibited across a face about 8 feet thick, although the rock is not uniformly saturated, the minerals being chiefly thin vein fillings in joints or cracks. Some portions of the rock are more richly impregnated, these being the thin-bedded, foliated material associated with the black carbonaceous plant remains. At this place copper minerals also show at a horizon whose beds outcrop 50 feet or more west of the prospect pit.

Some prospects were observed in secs. 22 and 15 north of the Bonneville claim, but the only other noteworthy showings of copper minerals found were those in Montpelier Canyon in and near sec. 34, T. 12 S., R. 45 E. The Montpelier Canyon prospects consist of a small group near the main road leading from Montpelier to Star Valley about 7 miles from Montpelier. The prospects here, as elsewhere, are in the Ankareh shale, showing dark-maroon and red shale, with some mottled red and light-greenish clay shale and associated red sandstones and limestone. The openings are not confined to the horizon so uniformly prospected farther south, but with the exception of a few pyrite specks in a massive limestone ledge at one of the prospects there appear to be no noteworthy indications of copper, except at the horizon previously described. The structure at this place is, however, more complicated and the attitude of the beds less easy to interpret with certainty. In this northern extension of the belt of copper prospects the overturned anticline already described appears to revert to the normal attitude a short distance north of the canyon of Montpelier Creek, and the overturned formations of the lower or eastern flank pass through some more local structural contortions and then merge into a broad syncline to the northeast, so that the outcrop of the Ankareh shale may be traced in a general way in two directions, toward Joes Gap on the one hand and northward on the other.

Several small prospects on the Evening Star claim, in the NW. ¼ sec. 34, T. 12 S., R. 45 E., show brecciated and copper-stained clay and sandy rock under a hanging wall of maroon shale, similar to the wall rocks of the copper ledge near the Bonanza claim. A sample taken by the author representing 14 inches across the face of a mineralized zone at the discovery monument on the Evening Star claim was tested, showing 2.85 per cent of copper. This specimen as collected afforded an impartial test, and undoubtedly consisted of somewhat leaner material than much of that shown at some of the prospects farther south. It may serve, however, as a conservative guide in estimating the general grade of the oxidized ores in this belt.

GENERAL SUMMARY AND CONCLUSIONS.

Deposits of copper in the "Red Beds" of presumed Triassic age belong to a well-recognized type. The constant association of copper minerals with carbonaceous matter, such as with coal or, as in this region, carbonized plant fragments, is considered good evidence that the carbon has acted as the precipitating agent which has caused the accumulation of the copper. It is assumed that copper may be or probably was present in widely distributed though minutely disseminated form in the sedimentary rocks as they were originally laid down. Such copper may have been taken into solution in the ground waters, to be precipitated again and concentrated when these waters came into contact with the carbon. It is known that organic matter acts as a reducing agent in some places, and that by its action sulphide minerals may be formed. Later oxidation of the sulphides has to a certain extent disseminated the carbonate minerals throughout the country rock, especially in brecciated zones. This theory is confirmed by the finding of chalcocite replacing the woody fibers of plant stems at the only place where these deposits have been opened in depth.

Prospecting in the green, maroon, and chocolate-colored shales of the Ankareh formation appears to be general throughout this region. On the whole it is probable that the vivid green color of some of the shales is too often mistaken for an indication of copper, and that the coloring substance is usually rather a form of iron, possibly reduced in association with organic matter, that gives on further exposure the dark-red and chocolate hues already described.

The copper minerals that have already been found may, however, prove to be of commercial value. Selected rock containing the copper carbonate minerals may be obtained to run 2 per cent or over, perhaps in considerable quantities. It is possible that such ore submitted to an economical process of leaching and precipitation by means of scrap iron or by electrolysis might be made to pay with efficient management.

The search for concentrated deposits in depth may be rewarded, but the chances are good that richer deposits if found will consist largely of chalcocite or chalcocite and covellite, for which other methods of treatment than those suggested above must be adopted.

THE COPPER DEPOSITS OF SOUTH MOUNTAIN IN SOUTHERN PENNSYLVANIA.

By GEORGE W. STOSE.

INTRODUCTION.

Copper ore and native copper occur in the pre-Cambrian eruptive rocks of South Mountain from the Chambersburg-Gettysburg pike in Pennsylvania into Carroll County in Maryland. In Pennsylvania the copper belt lies largely in Adams County but partly in the eastern portion of Franklin County. The ore is associated chiefly with the basic lavas and occurs generally at or near the contact with acidic lava. In most places the copper is found native in little blebs, grains, or wires. In some occurrences it is surrounded by the red oxide, cuprite, and at the surface and along joint planes it is generally altered to the brilliant green and blue carbonates, malachite and azurite, which stain large areas of the adjacent rocks.

GENERAL GEOLOGY.

The oldest rocks in the area are metamorphosed lavas of pre-Cambrian age. Two classes of these rocks are recognized—a basic rock, greenstone, which was derived from a basaltic lava by static or regional metamorphism, and an acidic eruptive derived from a rhyolitic lava by similar metamorphism. As both of these rocks show evidence that they were originally in large part of a glassy texture but have become devitrified by slow metamorphic processes during a long period of time, they are termed, respectively, apobasalt and aporhyolite. In this paper, however, the terms "greenstone" and "porphyry" will be used because they are less technical and are generally employed by the miners and prospectors.

The greenstone is both massive and schistose and usually all traces of its original character are lost. Numerous amygdules give evidence of the vesicular character of much of the original rock, and under the microscope other evidences of its eruptive character are shown. The original minerals have been almost entirely changed to epidote, chlorite, and quartz, with numerous minor accessory minerals, but in some specimens the basic feldspars are still preserved. In places large bodies or layers of epidote-quartz rock (epidosite) occur in chlorite schist, but in general these mineral segregations are small masses and amygdule fillings.

The porphyry is usually red, purple, or bluish in color and includes not only porphyritic lavas, but dense felsites and sericite schist. Most of the rocks are intensely squeezed and sheared and have acquired a slaty structure dipping to the southeast. The sericite schist is the extreme form of this dynamic metamorphism. Many of the felsitic and porphyritic rocks still preserve the flow banding of the original rhyolitic lava, which weathers in relief in minute wavy and crinkled lines. They also contain numerous spherulites and microscopic textures and inclusions that testify to their volcanic origin. Amygdules are not so plentiful in the acidic lava as in the basic. The minerals of the porphyry have not been altered as extensively as those of the greenstone, and chlorite and epidote are not common constituents of the rocks.

The distribution of the greenstone or copper-bearing rock is shown on the geologic map, figure 9. In the vicinity of the Maryland-Pennsylvania state line the greenstone covers a wide area in which lie small patches of the porphyry. From the distribution of these patches, which generally occupy crests of ridges or spurs, and the fact that both rocks are largely surface lavas and not intrusive, it appears that the porphyry overlies the greenstone and is younger. To the east this greenstone area ends abruptly where the mountains give place to the Triassic plain. On the north the greenstone is partly concealed by overlying Cambrian sediments, and beyond it is cut off by a diagonal fault running northeastward, the pre-Cambrian area north of the fault being occupied largely by porphyry. A rather wide band of greenstone continues northward in the direction of the strike of the rocks for several miles along the western margin of the pre-Cambrian area, and other long, narrow parallel bands lie inclosed in the porphyry. The relation appears to be one either of interbedding of the acidic and basic volcanic rocks or of intrusion of tongues of basic rocks into the acidic lava. On account of the excessive shearing, the original layering or bedding in the lavas can not generally be discerned, and therefore the relative age of the two lavas can not be positively determined, but it is tentatively concluded that the eruption of a great body of basaltic lava was followed by a large flow of rhyolite, which either was intruded by narrow sills of a later basic eruption or inclosed several thin recurrent basic lava flows.

These pre-Cambrian rocks were brought to the surface by a great uplift and the erosion of most of the covering of younger rocks.

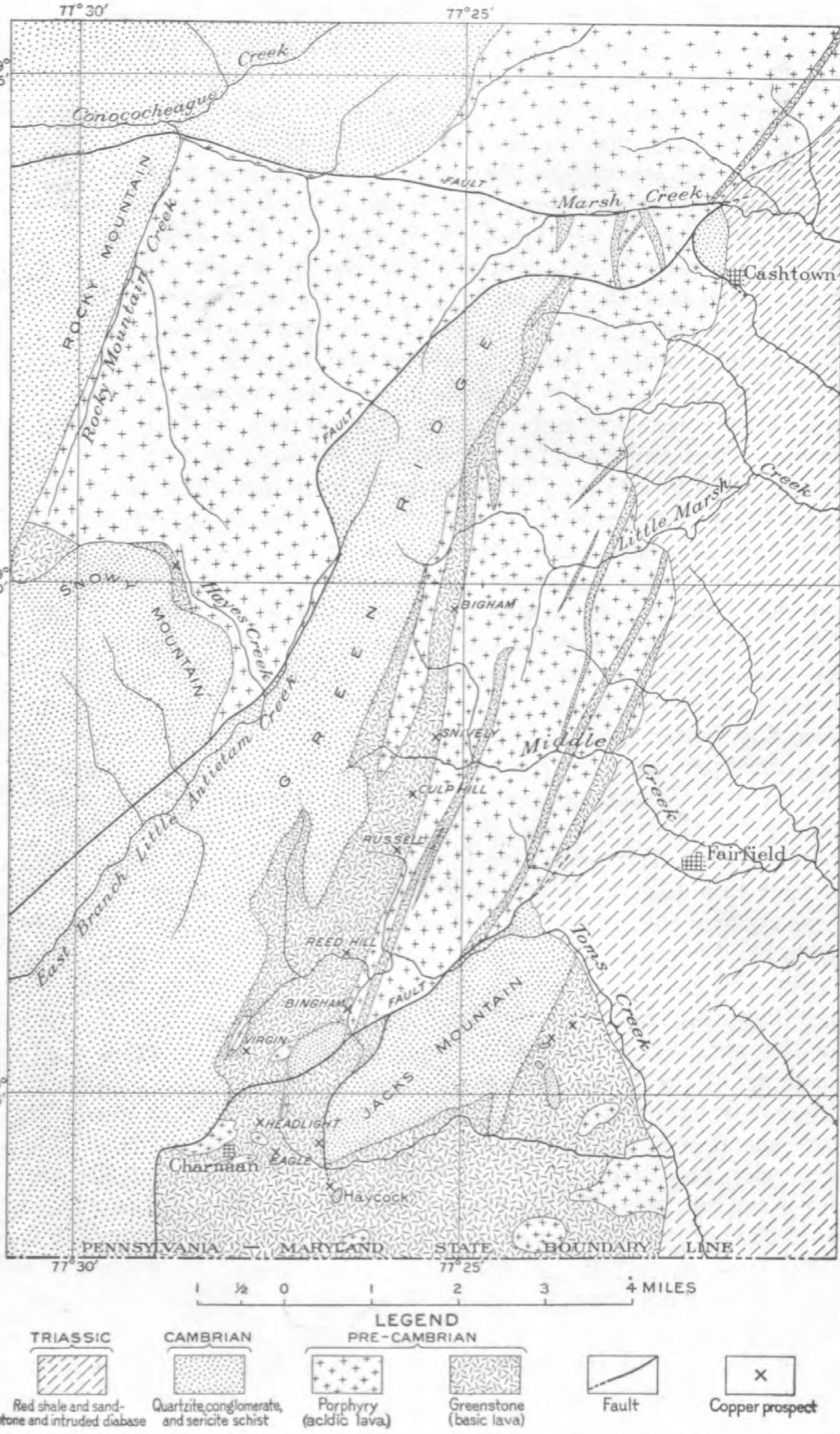

FIGURE 9.—Geologic map of part of South Mountain, southern Pennsylvania. By G. W. Stose.

Overlying the lavas are patches of quartzites, conglomerates, and sericite schist of Cambrian age, remnants of a cover that once extended entirely over the top of the fold. These Cambrian rocks appear in full force on the western flank of the uplift in Green Ridge, which limits the pre-Cambrian outcrops along a sharp line. The pre-Cambrian rocks reappear to the west, however, in another upfold of the uplift. The fine sericite schist and schistose arkose at the base of the Cambrian are followed by the hard conglomerate and quartzite that form the higher ridges and peaks of South Mountain.

ORE DEPOSITS.

The copper ore is associated chiefly with the basic lavas, but in a few places is found in the porphyry. It is further restricted chiefly, if not entirely, to the large greenstone mass, previously referred to as a large flow apparently underlying the porphyry, for copper is not known to occur in the narrow bands and tongues extending into the porphyry east of the main mass. Traces of copper are said to have been found along the entire belt from the Gettysburg pike to a point beyond the Maryland state line, the prospected properties merely being located at stream gorges, where exposures are better and the copper is more readily discovered. This belt of greenstone, therefore, is known to be copper bearing for at least 8 miles in Pennsylvania. Small prospects where only blue and green copper stain show at the surface have been opened at many places throughout the belt, but only those openings that are either of considerable size or expose a deposit of ore will be described. Those located in Maryland were not visited and will not be further referred to in this paper.

Virgin Copper Company.—At the present time the most actively worked property in the area is that of the Virgin Copper Company. It is located near the crest of a small hill 1 mile north of Charmian station, east of Gum Spring, on the Old Furnace road. Through the courtesy of Mr. C. E. Wills, manager, the mine was inspected and the following data were obtained.

A slope 215 feet deep enters near the top of the west side of the hill. The greenstone, which covers the top and east side of the hill, is chlorite schist with great masses and layers of epidote-quartz rock and small veins and nodular masses of quartz, epidote, and asbestos. About 80 feet below the mine, on the west side of the hill, occurs massive porphyry, and near the contact fragments of coarse amygdaloidal greenstone and breccia were found. At the mine entrance the greenstone is schistose and sheeted with epidote-quartz rock (epidosite) and stained with copper carbonate. The slope was started down the dip of the sheeted zone, but in depth the epidosite, with copper at intervals, occurs largely near and below the floor. At a depth of 150 feet a 10-foot drift to the west under the slope exposed the sheeted epidosite with calcite, chlorite, quartz, and strings of bright native copper. The copper is mostly in the chlorite schist, which is thickly impregnated for about 2 feet, but it also coats the sheeting and joint planes. The sheeted zone impregnated with copper had been previously encountered in two bore holes to the east of the slope, in one at a depth of 308 feet and in the other, farther east, at a depth of 600 feet. The 308-foot bore hole was reported to have passed through 7 feet of ore at the bottom. It is the intention of the owners to drift in at this level, as they believe that the ore at this depth will be rich enough to work profitably. Samples of the ore were not analyzed by the writer, as the run of mine could not be determined until drifting in the ore was begun. Picked samples from the pocket at a depth of 150 feet are rather rich.

The 6 by 8 foot slope is fitted with an 8-horsepower hoist and pump, iron skip car, and head frame, and two compressed-air hammer drills are in use. A good wagon road leads downhill to Charmian station and, if production warrants, an aerial carrier and gravity chute could be constructed down the east slope of the hill direct to the railroad at the foot.

Bingham mine.—Next north in this greenstone belt is the old Bingham or Copper Furnace mine, now being prospected by the National Copper Company. It is located about 1 mile northeast of the Virgin mine, in the porphyry on the eastern edge of the greenstone belt. Native copper occurs in the altered amygdaloidal rhyolite as small specks and blebs, surrounded by a zone of red oxide of copper. The joint planes are brilliantly stained blue and green by the copper carbonates, appealing to the prospector as representing large quantities of copper. The country rock is a beautiful fine, even-grained rhyolite, mostly drab with pink blotches, in part spotted with dark epidote-filled amygdules. The body of the rock is in places largely altered to epidote and quartz, derived from the adjacent greenstone. The opening consists of an open cut extending 40 feet into the hill and about 30 feet deep in the deepest part. An eastward-dipping crushed zone, composed partly of red clay, is exposed in the cut, and it is probable that the concentration of ore is associated with this channel for circulating waters. Samples from this mine are reported to have analyzed 4 per cent of copper, but the rock seen on the dump was too lean to constitute a workable deposit.

About the year 1840 this mine was developed by a Philadelphia company and worked for six months or so, the ore being smelted in a furnace on the property. The old workings and furnace have since entirely disappeared. J. T. Bailey[a] reported in 1883 a shaft 40 feet deep in quartzite (probably epidosite). He stated that the ore

[a] Copper deposits of Adams County, Pa.: Eng. and Min. Jour., February 17, 1883, pp. 88-89.

appeared to lie in three distinct veins upon the hill and that 4 or 5 tons of float ore had been shipped to a smelter for treatment.

Reed Hill mine.—One-half mile farther north in the greenstone belt, on the north slope of the Toms Creek valley, is an old prospect operated by the Reed Hill Copper Company. This lies in the center of the belt of greenstone, which is here in part dense, massive, and crystalline, in part scoriaceous and altered to epidote, quartz, and chlorite. Only copper stain was seen at the large opening, but at other small pits on the property the rock was peppered with native copper and cuprite.

An open cut runs 100 feet north into the hill and from it branch two tunnels 30 feet or more long. It has been closed down for two years, but the equipment is still in good condition and the tunnel open. Specimens of native copper weighing over 1 pound are reported to have been found in the soil and wash in this vicinity.

Russell property.—About 1½ miles northeast of the Reed Hill opening, at the place where Copper Run cuts across the greenstone belt, the copper deposits have been extensively explored on the old Russell farm. They are at present being exploited by the Reed Hill Copper Company, but active work was not in progress at the time of visit. Considerable development work has been done. A 6 by 12 foot double-compartment shaft 120 feet deep is well timbered and fitted with a double bucket hoist. Pumps are occasionally used to keep the water down. The shaft intercepts an older slope which enters about 200 feet to the west and is reported to run eastward from the bottom of the new shaft. The ore-bearing rock was reported by Henderson [a] to be 8 feet thick and to lie between two walls of chlorite schist. The ore is an amygdaloidal epidote-quartz rock, the amygdules being filled with epidote, red jasper, and calcite, in which are fine flecks of native copper.

The Bechtel shaft, another old opening on this property, is located a short distance to the northeast, at the contact of the greenstone and rhyolitic sericite schist. A large quartz vein lies in the schist parallel to the contact. Nothing is known about the ore from this shaft.

Snively mine.—About 1¼ miles farther north, where Middle Creek cuts across the greenstone band, the Snively or old Musselman Hill prospect is located high up on the north slope. Here are remains of two old shafts, one 53 feet deep, and a tunnel. The ore is reported by Henderson to occur in an 8-foot layer of epidosite lying between walls of chlorite schist that dip 52° SE. Samples of amygdaloidal greenstone altered to epidosite and impregnated with native copper and cuprite were obtained from the dump. Some of the finest

[a] Henderson, C. H., The copper deposits of South Mountain: Trans. Am. Inst. Min. Eng., vol. 12. 1883, pp. 85-90.

specimens of copper ore have been found as float on this property. Selected samples of the ore analyzed by Henderson gave 5.83 per cent of copper, but a careful sample made by him of the run of mine from the ore pile gave only 1.82 per cent. The less altered rock is a fine amygdaloid, the cavities being filled with quartz and bright-green epidote. It is near the contact with the rhyolite to the east, which is here a sericite schist, the same as at the Bechtel shaft, farther south. The schist has also been prospected near the stream level by a large tunnel, but no copper indications were seen. On top of Culp Hill, south of the creek, there is another prospect shaft, reported to be 22 feet deep and to lie in epidote rock between chlorite walls. A sample of ore from this shaft tested by Henderson gave 5.93 per cent of copper.

Copper stain was observed a mile west of the Snively mine, in an arm of greenstone that is separated from the Snively mass by a parallel band of porphyry and passes under the Cambrian sandstone of Green Ridge.

Bigham tract.—A mile and a half north of the Snively mine copper-bearing epidosite occurs at the contact of the greenstone schist and porphyry. The deposit has not been prospected. Similar copper-bearing rock is reported from the Bailey farm, 1 mile farther north, and the belt of greenstone with the same quartz-epidote rock that contains the copper continues in narrowing width to the Gettysburg pike.

Hayes Creek prospect.—Near the head of Hayes Creek a small area of greenstone emerges from beneath the Cambrian sandstone of Snowy Mountain in a branch anticline to the west of Green Ridge. This rock is a tough, fine-grained greenstone with masses of epidosite that contain in places native copper and cuprite. Some of the rock is finely amygdaloidal and brecciated. No deep excavations have been made here.

Eagle Metallic mine.—On Minie Branch, half a mile due east of Charmian, in the large greenstone area adjacent to the Maryland state line, the Eagle Metallic Company has put down a slope extending eastward at an angle of 35°, said to be 450 feet long. It enters at the contact of copper-stained massive epidosite with overlying highly altered and weathered chlorite schist. The dump showed vein quartz with specular hematite, chlorite, epidote, and copper-stained schistose greenstone. Chalcocite was reported to have been obtained at a depth of 100 feet.

The mine is equipped with a 20-horsepower engine, hoist, blower, pump, and air compressors, and although it was closed and full of water at the time of visit, the equipment was in good condition. The present company was being reorganized, and activity was to be renewed shortly.

Minor copper prospects in the large greenstone area to the east are located on the lower southern slope of Tunnel Hill and on the C. E. Wills farm, on the northern slope of Haycock, where copper-stained rock is plentiful on the surface.

Headlight mine.—An old tunnel, which enters the hillside just below the pike half a mile east of Charmian, was formerly very promising and actively prospected. It is 160 feet long and lies in quartzose greenstone impregnated with native copper. Bailey reported in 1883 that at a distance of 60 feet from the mouth of the tunnel an oblique impregnated chute was encountered, exposing an area of 24 square feet of ore-bearing rock, in which the copper was uniformly disseminated for a width of 5 feet, running 10 to 20 per cent. Later a second strike of rich ore was reported, but development work was shortly afterward abandoned.

Jacks Mountain shafts.—On the lower eastern slope of Jacks Mountain are several old caved-in shafts in the greenstone. The rock brought out is amygdaloidal and massive greenstone highly altered to epidote and quartz. Some amygdules are filled with specular hematite and epidote. Mineralization is indicated by copper stain, but native copper was not observed. No recent work has been done at this place.

ORIGIN OF THE ORE.

The segregation of the copper in its present form is undoubtedly secondary. The native copper is associated chiefly with epidote and quartz, secondary minerals derived from the alteration of basaltic lava. It has not been proved that the lava was originally copper bearing, but it is generally believed that minute particles of the metal, probably as sulphide, were disseminated through the basic flows as original constituents.

In pre-Cambrian time and again late in the Carboniferous the rocks were subjected to great compression and heat, and in the presence of heated waters the original minerals were altered. The hornblende or pyroxene was changed to chlorite. The basic feldspars and the ferromagnesian minerals reacted and formed a mixture of epidote and quartz, called epidosite. Much of the lava was vesicular and porous and furnished a passageway for circulating waters. Elsewhere the rocks were sheared and sheeted during the great dynamic alteration, and circulating waters followed these sheeted zones. Alteration was most active along these channels. Amygdules and cavities were first filled with various minerals derived from the original constituents, largely quartz and epidote, with some calcite, chlorite, and zeolites. In the most excessively altered portions the amygdaloid structure was entirely destroyed and the rock was changed to a massive epidosite. The disseminated copper in the original lava was concentrated during the process and is found as flakes in the filling of amygdules in the less altered rocks and on joint planes and as impregnations in the country rock in the highly altered zones in the epidosite.

The occurrence of many of the ore deposits at or near the contact of the acidic and basic eruptive rocks might be accounted for, if the later of the igneous rocks were intrusive, by assuming that the intrusion was accompanied by hot solutions that brought up the copper from deeper-seated sources. As it has been conclusively proved by microscopic examination that the larger areas of both these rocks with which the ores are associated were originally surface lavas, the occurrence is rather explained by the assumption that this contact marks the top surface of the basic flow, which was vesicular and porous in its upper portion and therefore subject to circulation of waters and consequent excessive alteration.

The transportation and concentration of the ore must have been effected by solution. The copper mineral, probably sulphide, originally disseminated in the lavas, was dissolved as sulphate and possibly changed to carbonate or silicate. The solutions, either oversaturated with dissolved minerals, lowered in temperature, or acted on by some precipitating agent, deposited the minerals on the walls of cavities and crevices. In one mine copper sulphide was reported, but all the samples seen by the writer were either native copper or its surficial derivatives, oxides and carbonates. It is probable that the copper was deposited from solution in the native state, like the rich deposits in the Lake Superior region, where native copper continues to great depth. Pumpelly[a] accounted for the deposition of native copper from solution on the assumption that the precipitation occurred in the presence of a strong reducing agent, such as the ferric oxide in the epidote and other ferriferous minerals with which the native copper is closely associated and which were probably formed at the same time. The higher oxidation of the iron in these minerals would be effected by the reduction of the copper oxide to native copper.

This theory of ore deposition has been tested in the laboratory and proved to be tenable. Stokes[b] has found that hornblende and siderite precipitate native copper from sulphate solution at 200° C.; that ferric sulphate, pyrite, and chalcocite reduce cupric sulphate to metallic copper under certain conditions; that hot cupric sulphate is reduced to cuprous sulphate by the addition of copper, and the solution when cooled gives off native copper, so that native copper could be deposited by hot solutions ascending to cooler levels.

It is generally conceded that epidote is essentially an alteration product. The massive layers of copper-bearing epidote and small

[a] Pumpelly, Raphael, Copper district: Geology of Michigan, vol. 1, pt. 2, 1873, pp. 1-47.
[b] Stokes, H. N., Econ. Geology, vol. 1, 1906, p. 648.

blebs of epidote and quartz in the center of relatively fresh rock are undoubtedly the result of deeper-seated alteration, under the influence probably of heated water, and it is concluded that most if not all the concentrated copper in the South Mountain district was deposited in this manner. As the metamorphism of these rocks and the production of most of the epidote occurred in pre-Cambrian time, the concentration of the copper in its present position and form must also have taken place at that time. This statement is at variance with the conclusions of Weed[a] and Phalen[b] in regard to similar occurrences of native copper in the same belt of pre-Cambrian volcanic rocks in Virginia. They regard the richer deposits as recent concentrations due to the downward percolation of surface waters, limited to shallow depth where leaching and concentration have gone on. The alteration of the country rock to epidote, quartz, and chlorite is also regarded by them as largely a surface phenomenon that accompanied the deposition of the ore. Minute disseminated specks of metallic sulphide, apparently chalcopyrite, were observed in the country rock from which it is believed that the concentrated copper deposits were derived.

FUTURE OF THE MINING INDUSTRY.

It is not possible to state what measure of success will be realized in the search for workable deposits of copper in this region. The fact that extensive and careful prospecting for seventy years or more has thus far not been rewarded is not encouraging to the miner. As the ores do not change in depth to sulphide, there is no hope of concentrated deposits in that direction. The ores occur sporadically along highly vesicular and shear zones, and the locations of deposits of sufficient concentration to be profitably mined can not be predicted, but can be ascertained only by actual prospecting and development. The present activity in a systematic search is to be encouraged in the hope of proving either the presence or absence of such workable deposits.

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[a] Weed, W. H., Copper deposits of the southern United States: Trans. Am. Inst. Min. Eng., vol. 30, 1900, pp. 449-504. Weed, W. H., and Watson, T. L., The Virginia copper deposits: Econ. Geology, vol. 1, 1906, pp. 309-330.

[b] Phalen, W. C., Copper deposits near Luray, Va.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 140-143.

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The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Those marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

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LEAD AND ZINC.

NOTES ON THE MINERAL DEPOSITS OF THE BEARPAW MOUNTAINS, MONTANA.

By Leon J. Pepperberg.

INTRODUCTION.

While engaged in an investigation of the Milk River coal field, Montana, during the field season of 1909, the writer had opportunity to visit a number of mineral prospects located in the Bearpaw Mountains. The following notes are the result of this rather hasty reconnaissance, which was made with the view of determining the probability of discovering valuable mineral deposits within the area. The most important work published by previous investigators on the geology of the region is that of W. H. Weed and L. V. Pirsson.[a] In this series of papers, which are based on a visit to the mountain group by Weed in October, 1895, the authors describe the prominent features of the region and give detailed descriptions of the occurrence and petrographic character of the specimens collected. Their studies show the Bearpaw Mountains to be rich in rocks of unusual types and of great interest and importance to the petrographer as well as the student of volcanic geology. Brief mention of the igneous rocks of the region is also made by Waldemar Lindgren,[b] who examined some specimens, mostly altered, collected by C. A. White in 1882 from the southern foothills of the mountains, in the vicinity of Eagle Creek. Some of the sedimentary rocks of this general region have been described by T. W. Stanton and J. B. Hatcher.[c] Their report, which deals with the geology and paleontology of the Judith River formation, contains a review and bibliography of publications relating

[a] The Bearpaw Mountains, Montana: Am. Jour. Sci., 4th ser., vol. 1, 1896, pp. 283-301, pp. 351-362; vol. 2, 1896, pp. 136-148, pp. 188-199.

[b] Am. Jour. Sci., 3d ser., vol. 14, 1893, p. 287.

[c] Geology and paleontology of the Judith River beds, with a chapter on fossil plants by F. H. Knowlton: Bull. U. S. Geol. Survey No. 257, 1905.

to this formation in Montana and Canada. The stratigraphy and occurrence of coal in the Milk River basin has been described somewhat in detail by the writer[a] in a preliminary report and the glacial geology of the region has been briefly discussed by F. H. H. Calhoun.[b]

The Bearpaw Mountains (fig. 10) are included in the Great Plains region of the Northwest and form one of a number of isolated mountain groups which rise abruptly from surrounding flat treeless plains. They lie in the southern half of Chouteau County, Mont., between Milk and Missouri rivers, about 20 miles south of the main line of the

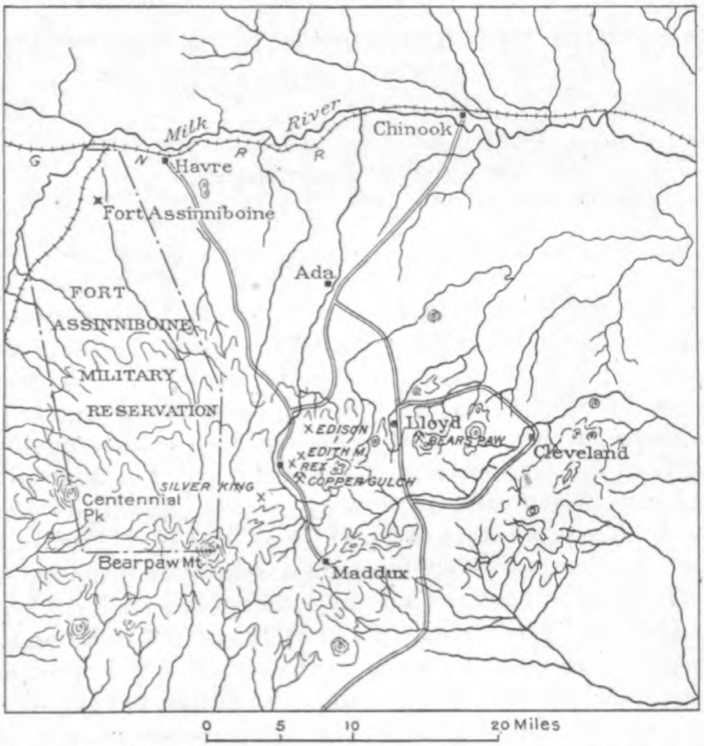

FIGURE 10.—Sketch map of the Bearpaw Mountains, Montana, showing location of the principal mines and prospects.

Great Northern Railway. The western and more mountainous part is included within the borders of the Fort Assinniboine Military Reservation. The Bearpaws do not constitute a true mountain range, but consist in the eastern part of a group of low rounded buttes more or less separated from one another, and in the western part of a series of dissected ridges gradually rising higher toward the west to their culmination in Baldy or Bearpaw Mountain and Centennial Peak. The mountain tract is about 45 miles in greatest length east and west

[a] The Milk River coal field, Montana: Bull. U. S. Geol. Survey No. 381-A, 1909, pp. 78-103.
[b] The Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906

and about 20 miles from north to south. Besides the main group and separated from it are numerous igneous buttes which rise above the plains, forming prominent landmarks. The region presents a type of mature topography. The highest point, Bearpaw Mountain, is about 7,040 feet above sea level. The surrounding plains have an elevation of approximately 3,000 feet above the sea, so that the area has a relief of about 4,040 feet. Except for some narrow flats along the main streams, almost the whole area is in slopes and all depressions are occupied by streams. The topography is clearly erosional and the drainage has advanced so far as to cause the development of slopes in every part of the district. This intense erosion has cut down the igneous necks and cores of the old volcanoes, leaving the narrow bands of metamorphosed sedimentary rocks surrounding them as high ridges and exposing the internal structure of the mountains.

The principal mineral prospects are located near Clear Creek and Lloyd, post-offices which are connected by stage with the railroad. One line of stage makes three round trips a week from Chinook to Ada, from which the mails are carried twice a week by separate lines to Clear Creek, Lloyd, and other inland post-offices located in the mountains. The trip to the mountains is made in one day from Chinook or Havre.

The writer is indebted to Messrs. Weed and Pirsson, whose valuable geologic data have been freely incorporated in this report; to the prospectors and ranchers of the district, who have been uniformly courteous in facilitating his investigations; and to Mr. C. E. Siebenthal, whose friendly interest and suggestions have been of great value and assistance.

HISTORY OF DEVELOPMENT.

The placer deposits of the Bearpaw Mountains are of very little importance, although some coarse gold has been recovered by panning and crude sluice methods from the small gravel bars occurring along drainage ways throughout the group. Since the early seventies prospectors have searched the mountains for lode deposits, and although several pieces of promising looking float which were reported as having been picked up within the district were brought to Havre and Chinook, no vein of value was discovered until about 1888. In that year work was begun on an argentiferous galena vein about 3 miles southeast of Lloyd post-office, by a number of Chinook business men. Development was continued on this vein for about four years after the discovery and, according to L. V. Bogy, of Chinook, who is interested in the property, about 7 tons of sorted ore was shipped to Great Falls for treatment. In 1892 the claim was patented and since that time no work has been done on this property. In 1906 Stephen Randall discovered a vein of supposed copper ore about three-fourths of a mile southeast of Clear Creek post-office. Immediately after this discovery the Copper Gulch Mining Company, of Chinook, was formed to develop a group of claims staked out by Randall and his associates. The shaft sunk on the site of the original discovery showed the vein to carry values in lead, silver, gold, and copper, and as a result of this showing much prospecting was done during 1906 and 1907 along the tributaries of Clear Creek, especially around the head of White Pine Cañyon. The district is not a producer at the present time. The locations of the prospects are shown in figure 10.

GEOLOGY.

Weed and Pirsson have shown that the Bearpaws are not a mountain range of folded sediments but consist of the dissected remains of a group of volcanoes of Tertiary age. Intense erosion has laid bare the internal structure of the group, leaving the tilted, altered sediments as ridges and buttes which are cut by dikes and sills, while the upper parts of the volcanic necks and stocks have for the most part been carried away, being more easily attacked than the metamorphosed sediments. These stocks and cores now make up the slopes along the ridges that are formed partly of altered sediments.

The igneous rocks are of various kinds and include representatives of both extrusive and intrusive types. The effusive rocks are widespread and make up the larger portion of the igneous rock of the district. They form the highest peaks, small chains of hills, and outlying isolated buttes, and represent remnants of the large area originally covered by the extrusive material. These rocks consist for the most part of leucite basaltic tuffs, breccias, and lava flows of dark color. The colors vary from greenish-black tints through the purples, reds, and browns. In texture the rocks range from hard, tough, compact varieties showing no porphyritic crystals to highly porphyritic forms which become porous and grade into scoria.

Intrusive rocks of many interesting and unusual types occur within the group as dikes, sills, small laccoliths, stocks, and volcanic necks. Among these rocks as determined by Weed and Pirsson are mica andesite or mica trachyte, quartz syenite porphyry, augite syenite, leucitite, nephelite basalt, potassium tinguaite porphyry, quartz tinguaite porphyry, pseudoleucite-sodalite tinguaite (a bright-green porphyritic rock), and numerous others, including shonkinite, a dark augite-olivine-biotite-orthoclase rock. The intrusive rocks vary in color from cream and gray through red, brown, and bright greens, mottled by crystals of varicolored minerals that contrast with the predominating shade of the groundmass.

No signs of local glaciation were observed within the mountains, although they are shut in on all sides except the south by the terminal moraines of the Keewatin ice sheet.

The sedimentary rocks outcropping within the mountains are largely of Cretaceous age, but some Tertiary rocks were observed west and north of Centennial Peak. The Cretaceous rocks are represented within the mountainous tract by the dark Colorado shale and local outcrops of Eagle sandstone. The strata outcropping in the plains surrounding the mountains are given in the following table:

Stratigraphy of the Bearpaw Mountain region.

System.	Group or formation.		Thickness.	Description.
			Feet.	
Quaternary.				Alluvial deposits; glacial drift.
Tertiary.	Fort Union formation.		60+	Massive gray to buff sandstone with thin beds of gray shale, containing many fossil plants and workable subbituminous coal beds.
Cretaceous.	Montana group.	Bearpaw shale.	80-100	Leaden-gray shale, with thin beds of sandstone and large concretions, usually fossiliferous.
		Judith River formation.	480	Alternating beds of light-colored sandstone and shale; workable subbituminous coal beds within the upper 150 feet.
		Claggett formation.	350±	Dark-gray shales with thin beds of buff sandstone near top and bottom and large concretions, in places fossiliferous.
		Eagle sandstone.	250	Massive, slightly calcareous white to cream colored sandstone locally cross-bedded; at top, dark-gray shale, with intercalated beds of gray to buff sandstone.
	Colorado shale.		1,000+	Drab or lead-colored clay shale carrying round or oval concretions of gray limestone.

The sedimentary rocks, which surround the larger bodies of intrusive rocks and are cut by dikes and sills, generally show the effect of contact metamorphism. The shales have been indurated and altered to such an extent that slaty cleavage has developed; the sandstones are converted to quartzite and the limestones to impure marbles. The baking has changed them to hard, compact, flinty rocks of various shades of lavender, red-brown, lead-gray, green, and white streaked with gray laminæ, and in many places cubical jointing has developed.

Although these metamorphosed sediments break into small irregular fragments, they resist erosion better than the igneous rocks which they surround and form some of the principal ridges and divides of the region. The igneous rocks usually make up the slopes adjacent to the altered sediments.

The thickness of the rocks which show the effect of metamorphism varies with the size and character of the intrusion. The more highly altered sediments are in contact with eruptive rocks of basic types.

ORE DEPOSITS.

OUTLINE OF OCCURRENCE.

The earliest prospecting in the Bearpaw Mountains was induced by the small pieces of gold-bearing quartz float and colors which were obtained by panning small bars along coulées within the group. Numerous veinlets and stringers of quartz and calcite and a few of barite have been prospected, and although some of these carried small values in gold, as yet no important gold discovery has been reported.

The principal mineral prospects are located on the peripheries of old volcanic necks and stocks within the zone of altered sediments. These metamorphosed shales, with the intruded dikes and sheets, form some of the principal ridges and divides of the district. The mineralization occurs along shear zones, breccia zones, joints, and small fractures that are in part due to the intrusion of the igneous masses. The ore minerals consist almost entirely of sulphides, which were probably precipitated from hot ascending waters. The veins are usually associated with dikes or sills which cut the sediments and both intrusive and extrusive igneous rocks.

The most valuable ore deposits so far discovered contain argentiferous galena carrying some gold, the associated vein minerals being quartz, calcite, zinc blende, pyrite, chalcopyrite, barite, pyrrhotite, and arsenopyrite. The mineralized veins range from mere seams to veins more than 20 feet in thickness, but the average width of all veins examined was less than 1 foot. Some of the veins can be traced for several hundred feet along the surface, but in other localities there has been a considerable amount of faulting along planes at various angles to one another and this obscures the continuity of the veins.

The walls of a few of the veins are fairly well defined for short distances, but many of them show no distinct boundary between the vein material and the country rock. In those of the latter class brecciated country rock is in places included within the vein matter or the mineralization has been diffused along minute fractures extending into it. Although the mineralized veins and veinlets run in various directions, those which carry the greater values have a northeast-southwest trend.

DESCRIPTION OF THE PRINCIPAL DEPOSITS.

There has been considerable prospecting in the Bearpaw Mountains during the last twenty years, but comparatively few important discoveries have been made. No mine in the district can be classed as a producer, although several tons of galena have been shipped from the Bear's Paw mine. The most important ore bodies are described below.

BEAR'S PAW MINE.

The Bear's Paw mine (sometimes called the O'Hanlon mine) is in the NE. ¼ sec. 19, T. 29 N., R. 19 E., about 3 miles southeast of Lloyd post-office. It is located on the summit of a high butte (elevation 5,000 feet by aneroid barometer) which forms a part of the divide between Snake and Peoples creeks and is about 2 miles east of the old Lloyd-Nelson mail road.

The Bear's Paw was discovered in 1888 by a miner who had been prospecting in the mountains for a number of years. Several business men of Chinook obtained an interest in the property by furnishing funds for its development. They worked the property from time to time for about four years and were granted a patent in 1892. Very little work has been done on the property since that date, and in August, 1909, at the time it was visited by the writer, the shaft house which once formed a prominent landmark and could be seen for miles from the surrounding plains had been blown down and the shaft was in such poor condition that it could not be entered.

Mr. L. V. Bogy informed the writer that the original plan was to sink a shaft following the ore, which was supposed to be an almost perpendicular vein with regular walls. Within the first 70 feet the vein changed direction several times, so that it was necessary to abandon the plan of following the ore and the remaining 100 feet was sunk vertically after partly straightening the upper part of the shaft.

Several small drifts were made at intervals in the shaft to tap the vein. Mr. Bogy also reports that the vein is from 4 to 5 feet wide and contains several rich pay streaks from 2 to 6 inches wide. About 7 tons of this rich ore was sorted by hand, hauled to Chinook by wagon, and shipped to the smelter at Great Falls, where a mill-run test was made which showed the ore to carry about 50 ounces of silver to the ton, 50 to 60 per cent of lead, and a little gold.

The igneous rocks associated with the ore body are described by Weed and Pirsson[a] as follows:

> The ore body occurs near the margin of an intrusive mass of trachyte, which, as is commonly the case in these mountains, has been deeply cut by the drainage, while the contact zone with its denser rock and rim of hardened sediments stands out in relief, forming the summit of the butte and its most important westerly spurs. The main mass of the rock is a trachyte, generally much altered, in which large crystals of white feldspar occur in a reddish-yellow groundmass. Good exposures of the intrusive mass are rare even where the slopes are deeply cut by drainage channels, for the prevalent covering of grass, everywhere a feature of the mountains, often conceals even the débris. The rock is a trachyte or syenite porphyry which is too greatly altered and decomposed to be of value for petrographic study. It consists of a brownish, earthy feldspathic groundmass filled with limonite and with hollow cavities caused by weathering and decay of a former iron-bearing mineral. This is thickly filled with feldspar phenocrysts of a thick tabular or short columnar habit about 1 cm. in greatest

[a] Am. Jour. Sci., 4th ser., vol. 1, 1896, pp. 299-301.

length. Its determination as a rock of the alkali class rests upon the character of its contact form.

The contact form of the trachyte is a dark greenish-gray rock thickly crowded with small idiomorphic feldspar phenocrysts of thick tabular form. There is a sprinkling of rather dull inconspicuous black dots which are either pyroxene or micas. * * *

The shaft of the mine has been sunk upon a mass of shonkinite, a dark basic micaceous rock which appears to form a dike cutting transversely across both the periphery of the trachyte intrusion and its marginal zone of hardened, baked sedimentary rocks. This rock is of a moderately coarse grain and is filled with stringers and thin seams of pyrite. It consists of iron ore, apatite, augite, biotite, and soda orthoclase feldspar. It is moderately coarse-granular, and the augite and biotite, which are the chief ferromagnesian minerals, are inclosed poikilitically by the alkali feldspar in broad plates. * * *

The gangue of the ore body is a brecciated and much altered trachyte or syenite porphyry. The fragments composing it are angular, of varying size, color, and character, and the rock shows considerable pyrite scattered throughout its mass. Examined under the microscope, the thin section shows untwinned feldspar phenocrysts, biotite, and iron ore in a feldspathic groundmass consisting apparently of singly or untwinned alkali feldspars. It is now so greatly altered by leaching solutions, filled with calcite, which exists everywhere in thin films, and the feldspar is so changed into sericite that it would not be safe to assert more than this about it.

Small crystals of slightly oxidized galena and pyrite were found in place on the surface of the igneous and metamorphosed sedimentary rocks which make up the butte on which the shaft is located. The butte consists of metamorphosed shales, slightly calcareous in part and containing some sandy members, intercalated with sills of igneous rock and cut by numerous dikes. The alteration of sedimentary and intrusive rocks gives the surface a ribboned appearance. The strike of the vein is N. 40° E. The dip could not be measured but is close to vertical. A part of the brecciated gangue is probably made up of altered sediments similar to those exposed in the vicinity of the mine shaft. Specimens found on the dump indicate that the richer streaks of argentiferous galena occur in pockety geodic masses in the vein, as numerous pieces of pure galena up to 3 or 4 inches in size were observed. The main vein material, however, consists of quartz and calcite, somewhat banded and impregnated with small crystals of galena, pyrite, iron ore, and scattered crystals of chalcopyrite. This material, which probably forms the greater part of the lode, could be easily crushed and concentrated. The high-grade ore now lying on the dump indicates that further prospecting is warranted.

COPPER GULCH GROUP.

The Dividend claim, on which the shaft of the Copper Gulch Mining Company of Chinook is located, is one of a group of eight claims constituting the property of this company. This claim is located on the west slope of Greenough Butte, near the head of Copper Gulch, about half a mile east of the Clear Creek and Maddux mail road and about 35 miles south and a little west of Chinook. It was discovered in 1906 by Stephen Randall, who while looking for some cattle accidentally noticed a piece of rock that he thought might carry values. Samples collected by Randall were sent to Butte and to Great Falls for assay and showed the rock to be copper bearing. After prospecting the property business men from Chinook became interested in it and formed the Copper Gulch Mining Company to develop the group of claims. Active work was commenced in 1907, when a force of men constructed a road connecting the prospect with the Clear Creek county road. The mine workings consist of a 4 by 8 foot shaft, 108 feet in depth, from the bottom of which a drift runs 27 feet to the north, tapping the vein, which dips 70° N. 40° W.

The mineralization here, as in the Bear's Paw mine, occurs in the metamorphosed rim of a stock. The general country rock consists of a fine-grained gray augite syenite. The ore is found along fracture and shear zones in a dike of syenite porphyry. This rock, which has

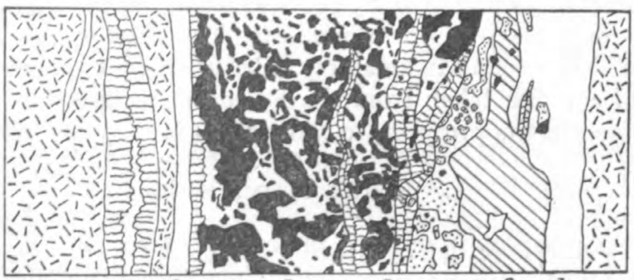

FIGURE 11.—Cross section of banded vein on property of Copper Gulch Mining Company, 35 miles south of Chinook, Mont. *a*, Country rock; *b*, calcite; *c*, quartz; *d*, galena with calcite and quartz; *e*, zinc blende with calcite and quartz; *f*, pyrite and chalcopyrite.

a greenish-gray color, is fine grained and examination of the thin section shows that it is badly altered by leaching solutions. It is made up largely of biotite, hornblende, orthoclase, plagioclase, and quartz, with secondary quartz and calcite veinlets and scattered pyrite crystals occurring along minute fractures. The ore-bearing portion is 4 to 5 feet in width and consists of several stringers of argentiferous galena from half an inch to 6 inches thick. The associated minerals are quartz, calcite, zinc blende, pyrite, and chalcopyrite. The vein shows distinct banding and in many places comb structure is well developed, as illustrated in figure 11. The ore deposited in open spaces shows evidence of subsequent crushing. In the altered, bleached, and highly calcareous country rock small grains of pyrite and galena have developed.

Although the property was thought to be copper bearing when discovered, it has proved to carry mainly silver and lead. Only small amounts of copper minerals were observed by the writer. Numerous assays of samples sent in for analysis show the ore to carry from 40 cents to $9 in gold and as high as 41 ounces of silver to the ton, up to 10 per cent of copper, and from 6 to 50 per cent of lead. The ore-bearing portions of the vein are well mineralized and could be easily crushed and concentrated.

EDISON CLAIM.

The Edison prospect is located in the SE. ¼ sec. 14, T. 29 N., R. 17 E., at the head of Spencer Gulch. At this place a 10-foot prospect pit has been sunk on a vein of barite and calcite along a brecciated zone in a highly micaceous brownish to gray dike. The mineralized zone is about 3 feet thick and consists of several small stringers connected by branching veinlets along small fractures. It has been altered by oxidizing solutions and the brecciated portion contains pieces of metamorphosed limestone and numerous cavities filled with quartz crystals. No pyrite was observed in this prospect, although oxidized iron ore is present. The chief values lie in the galena, which is found in small crystals throughout the vein matter. Assays of samples taken from the Edison claim are said by C. W. Allen, owner of the prospect, to show $6.90 in lead and silver to the ton.

REX CLAIM.

The Rex prospect is situated in the SW. ¼ sec. 27, T. 29 N., R. 17 E., and consists of a 47-foot tunnel driven on a vein of pyrrhotite, a bronze-yellow magnetic iron sulphide of metallic luster with a dark tarnish. At the breast of the tunnel 25 inches of almost solid ore was measured, and to judge by surface indications the vein is 18 to 20 feet in width. It consists almost entirely of pyrrhotite, carrying a trace of nickel. This ore is of interest, for examination of a thin section shows it to be clearly a magmatic deposit. The associated minerals are pyrite, chalcopyrite, and augite that is partly altered to hornblende and calcite. Some garnet has developed. The country rock is a dark basic micaceous dike. The vein stands almost perpendicular and strikes N. 60° E. It is said to carry values in gold and silver ranging from $2 to $10 a ton.

EDITH M. CLAIM.

The Edith M. prospect is located about 200 yards east of the Rex. It consists of a 10-foot pit sunk on a quartz-calcite vein of which a dike is the hanging wall and a metamorphosed impure limestone the foot wall. The vein is 10 to 22 inches in width. It has been altered by surface waters and although in the hand specimen the mineralization seems to be slight, an assay by Raumbauer & Co., of Butte, Mont., for C. Measles, owner of the prospect, shows it to carry the following values: Copper, 8.33 per cent; gold, $10.80 to the ton; silver, 14 ounces to the ton.

SILVER KING CLAIM.

The Silver King prospect is one of many openings made near the head of White Pine Canyon. It is situated on the spur between the main and middle forks of the canyon and consists of a 15-foot pit sunk on a small quartz vein 4 to 5 inches wide. The ore consists of argentiferous galena associated with pyrite, calcite, and quartz. The richer portions occur in small pockets, but the entire vein is mineralized. An assay made by Fisk & Co., of Helena, Mont., of a sample which F. B. Rodgers, of Maddux, owner of the prospect, informed the writer represented an average of the vein, gave the following results: Lead, 23 per cent; silver, 62.84 ounces to the ton; gold, 40 cents to the ton.

BLACK DIAMOND CLAIM.

The Black Diamond prospect is located close to the Silver King, on the spur between the main and middle forks of White Pine Canyon. It is not shown on the accompanying map. It consists of a 14-foot pit sunk on a vein of high-grade magnetite 14 to 20 inches thick. Examination of the thin section shows the ore to be a magmatic deposit. The associated minerals are apatite and augite. The country rock is a dark basic micaceous dike. This ore, like that in the Rex prospect, is of interest because it is purely an igneous product and shows that the intrusive rocks of the shonkinite type contain metals as sulphides and oxides which separate out, forming ore bodies where proper conditions are present.

CONCLUSIONS AND SUMMARY.

The mineralization in the Bearpaw Mountains is widely diffused, as comparatively few localities have been discovered where there has been sufficient concentration to form ore bodies. This is shown by the fact that though numerous openings have been made on veins and veinlets throughout the district only a small number of promising prospects have been found. The banded and comb structure of the veins points to the precipitation of the deposits by hot ascending solutions. The deposits have been altered more or less by descending waters. As previously stated, the Bearpaw Mountains are in a mature stage of erosion; consequently any mineral veins exposed in them can be considered as representing parts of ore deposits that extended upward for several hundred feet prior to the denudation of the region. In other words, the veins of the district represent the roots of former more extensive ore deposits.

The Bearpaw Mountains are not heavily timbered but furnish a sufficient quantity of pine, fir, and aspen to meet the requirements of a small number of mines. Clear, Bean, and Snake creeks carry sufficient water for mining and milling purposes, and coal is abundant in the Judith River formation, 15 miles north of the mountains.

The ores of the region could be easily concentrated and it is possible that future prospecting may develop ore bodies of some value.

SURVEY PUBLICATIONS ON LEAD AND ZINC.

The following list includes the more important publications on lead and zinc published by the United States Geological Survey. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ADAMS, G. I. Zinc and lead deposits of northern Arkansas. In Bulletin 213, pp. 187–196. 1903. 25c.

ADAMS, G. I., and others. Zinc and lead deposits of northern Arkansas. Professional Paper 24. 118 pp. 1904.

BAIN, H. F. Lead and zinc deposits of Illinois. In Bulletin 225, pp. 202–207. 1904. 35c.

——— Lead and zinc resources of the United States. In Bulletin 260, pp. 251–273. 1905. 40c.

——— A Nevada zinc deposit. In Bulletin 285, pp. 166–169. 1906. 60c.

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RARE METALS.

NOTES ON THE OCCURRENCE OF CINNABAR IN CENTRAL WESTERN ARIZONA.

By HOWLAND BANCROFT.

During the spring of 1909 the writer made a reconnaissance of the economic geology of central western Arizona, examining, among other deposits, the well-known[a] cinnabar prospects near Quartzite. Because of the scarcity of this mineral in Arizona and the lack of any scientific literature on these occurrences, it has been thought advisable to publish a brief preliminary description of this district. Development work has not been very extensive in the vicinity, and the results of the investigation are interesting mainly from the standpoint of the mineralogist and geologist.

The deposit is located in the Plomosa mining district, Yuma County, Ariz., in the southern part of the Dome Rock Mountains, some 8 miles due southwest of Quartzite, at a place locally known as Cinnabar. Vicksburg, on the Arizona and California Railroad, is the most accessible station, and in an air line is just 28 miles a little north of west of Quartzite, the stage road between the two places being a few miles longer.

During the summer months the heat is more intense in this vicinity along Colorado River than in any other part of the United States. Timber for use as fuel and water for domestic purposes are obtained in the vicinity, though neither is found in great abundance.

The topography is characterized by broad, flat valleys with mountain ranges rising abruptly from the deserts. The Dome Rock Mountains have an average elevation of 1,500 feet, being approximately 1,000 feet above the surrounding country. The spur in which the cinnabar occurs forms the highest branch of the mountains, one of its peaks rising to an elevation of over 2,700 feet. The dip of

[a] These deposits, according to H. W. Turner, have been known for over thirty years. See The mineral industry during 1908, Quicksilver, p. 743.

the strata in the vicinity of the deposits is in general between 15° and 45° NE., and the strike is to the northwest, but there are many pronounced local changes in both dip and strike.

The rocks in this locality are arenaceous shales, presumably of pre-Cambrian age, which have been metamorphosed into quartz-mica schists. To the unaided eye most of them appear fine grained, with a satiny sheen, ranging in color from light silver-white through gray, brown, and red to a dark, almost black tone. The colors are due in general to the kind of mica and the amount of chlorite and epidote present and in part to the degree of oxidation of the contained iron. Mica is prominent, and although the crystals are not large they are conspicuous enough to be recognized without the use of a strong lens. Because of their abundance, the rocks are fairly soft, feel greasy, and are readily scratched with a knife blade. On microscopic examination of thin sections it is found that the general composition of the schists is the same; all of them contain much quartz, feldspar, and mica, part of the mica probably resulting from the decomposition of the feldspars. Epidote is present in almost all the schists, and some of them are highly chloritic. Near the veins the wall rocks show calcite and epidote in abundance, with some zoisite.

The country rock in which the deposit worked by the Colonial Mining Company occurs is unlike most of the schists in the vicinity in that it contains small crystals of magnetite scattered throughout the rock in large quantities.

In a prospect owned by the French American Mining Company, located a short distance from the one just mentioned and in a similar series of rocks, there are, associated with pure white quartz, small quantities of tourmaline, gold, and copper glance, all except the last apparently of primary origin. Siderite associated with gold was noted, and cinnabar is said to occur with the tourmaline in the quartz, although none was to be seen at the time of the writer's visit to the property. The vein strikes N. 55° W. and dips about 15° SE., cutting directly across the schists, which dip 20° to 30° N. 60° E. A variety of the schist next to the vein is highly impregnated with tourmaline; another schist in the vicinity is extremely silicified, and very impure limestones occur near by. The association in this vein of primary quartz, tourmaline, and gold is indicative of deposition under great heat and pressure.

The vein worked by the Colonial Mining Company strikes S. 55° E. and is practically perpendicular. It occupies a fault zone which shows intense brecciation of the country rock. The gangue is highly siliceous and is cut by small stringers of calcite and siderite, the former occurring in places in conspicuous quantities, but being entirely absent in the croppings of the vein, where silica with a little black oxide of manganese forms the ledge. In width the vein varies from a few inches to several feet; parallel breccia planes of small magnitude, which accompany the main fault in places, tend to widen the deposit. The ore shoot in the property is said to pitch to the southeast.

Cinnabar is very sparsely distributed throughout the gangue and is supposed to be found mainly on the northeast side of a very plastic, iron-stained gouge which has resulted from the extreme movement in the fault zone. The ore in places is conspicuously marked by the green carbonate of copper, and Turner[a] has reported gold and silver in ores from this deposit. The presence of magnetite near the vein is a feature worthy of note; its alteration has probably formed the red and yellow stains so common in the brecciated vein material and gouge.

Considering the facts that late eruptions are absent in the vicinity, that the deposit is entirely oxidized, that copper stains are prominent, and that values of gold and silver occur in the vein, it seems highly probable that the cinnabar has been derived from mercurial tetrahedrite.[b]

The Colonial Mining Company has a vertical shaft about 300 feet deep with three levels, constituting in all some 1,500 feet of development work.[c] During parts of 1908 a 30-ton Scott tile furnace was operated on the property, and the recovery of a small amount of mercury was reported.[d] High absorption of the metal by the bricks of local manufacture used in the condensers is reported by the management to have so lowered the percentage extracted that metallurgical operations have not proved profitable.

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[a] Turner, H. W., The mineral industry during 1908, Quicksilver, p. 743.

[b] For this suggestion pertaining to the origin of the cinnabar the writer is indebted to Mr. Waldemar Lindgren, who has noted the occurrence of this mineral in gold-quartz veins of the Granite district, Blue Mountains, Oregon, containing also pyrite, chalcopyrite, and arsenopyrite. See The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 683.

[c] These figures are only approximate.

[d] McCaskey, H. D., The production of quicksilver: Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 692.

SOME OCCURRENCES OF MOLYBDENITE IN THE SANTA RITA AND PATAGONIA MOUNTAINS, ARIZONA.

By F. C. Schrader and J. M. Hill.

LOCATION AND GENERAL DESCRIPTION.

The Santa Rita and Patagonia mountains constitute one of the most prominent mineral-bearing desert ranges of the Southwest. Beginning near the transcontinental line of the Southern Pacific Railroad about 20 miles southeast of Tucson, the range extends southward in Pima and Santa Cruz counties, with a length of 45 miles, to the international boundary, which it crosses about 12 miles east of Nogales. The northern two-thirds of the range, extending to Sonoita Creek, which cuts across it, is known as the Santa Rita Mountains and the remainder as the Patagonia Mountains.

The range is generally rugged and near the middle part of its course culminates in Old Baldy, at 9,432 feet above the sea. It is drained by Santa Cruz River, which flows in a northwesterly direction via Tucson into the Gila, which in turn joins the Colorado at Yuma

In a reconnaissance of the mineral deposits of the mountains during the season of 1909 the occurrences of molybdenite (sulphide of molybdenum, MoS_2) herein described were encountered at the following more or less widely separated localities, as indicated on the accompanying map (fig. 12): Helvetia, Madera Canyon, Providencia Canyon, Duquesne, and near the international boundary Of these the most important is Helvetia.

DESCRIPTION BY LOCALITIES.

HELVETIA.

Helvetia, the most important mining camp in this part of Arizona, is situated 27 miles southeast of Tucson, in the northern part of the Santa Rita Mountains, on the west slope at an elevation of about 4,300 feet. (See fig. 12.) Here molybdenite occurs at two localities—the Leader mine and the Ridley mine.

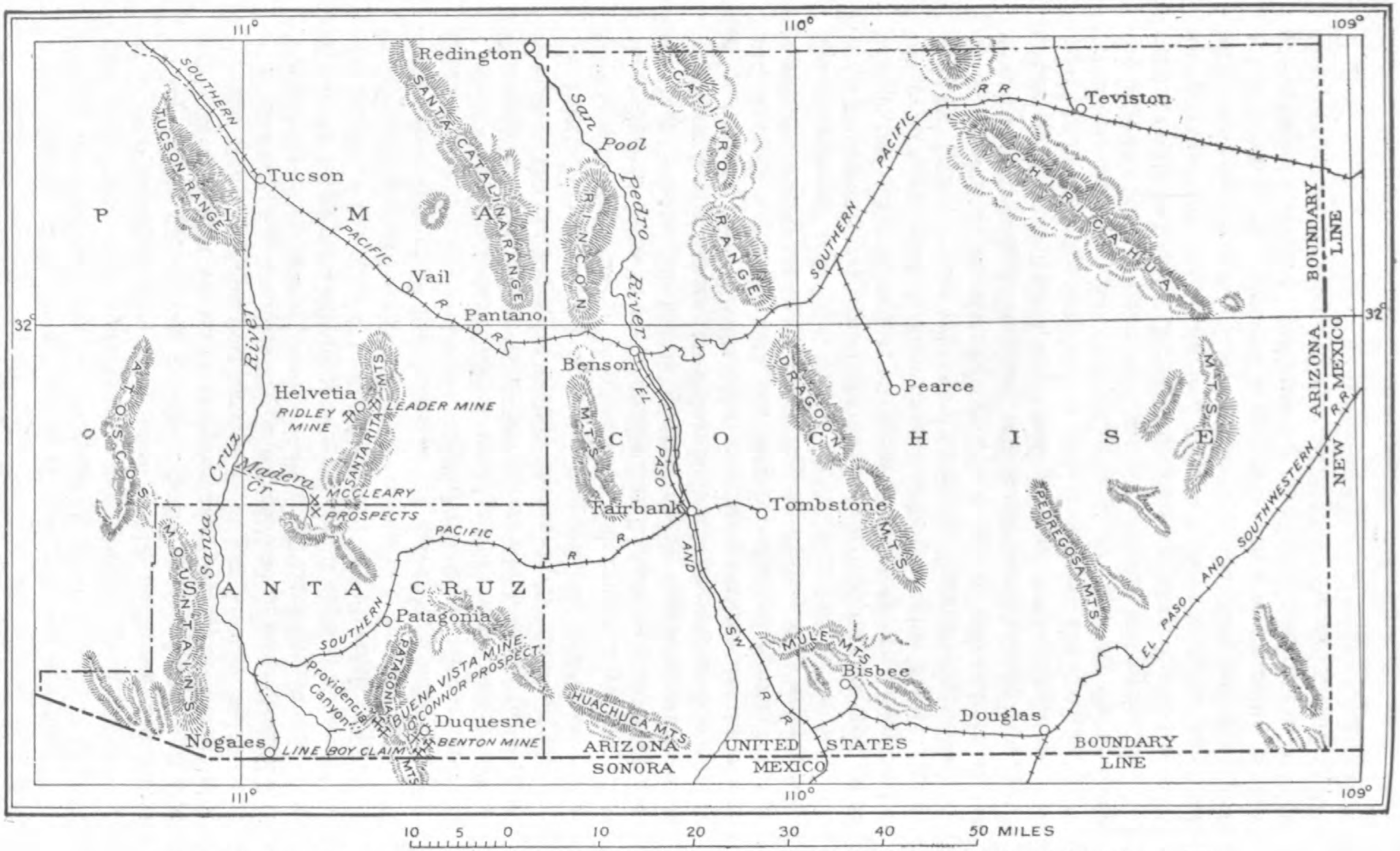

FIGURE 12.—Index map of southeastern Arizona, showing location of molybdenite deposits in Santa Rita and Patagonia mountains.

LEADER MINE.

The Leader mine, one of a group of copper mines owned and operated by the Helvetia Copper Company, is situated east of the town and a few hundred feet above it, at an elevation of about 4,700 feet, in altered Paleozoic limestone, close to the northeastward dipping contact with underlying granite. Both pre-Cambrian and post-Carboniferous granitic rocks are present. The latter include aplite dikes as well as granite porphyry.

The workings in the main are on what is known as the tunnel level, which follows the contact for some distance, extending in a northerly direction. The molybdenite occurs at a point about 150 feet in from the mouth of the tunnel, in dull-brownish and greenish to yellowish mineralized garnetiferous silicified limestone and quartz.

The rock is more or less massive. It varies from fine to medium grained and is composed essentially of pale-greenish garnet, which corresponds to grossularite and occurs in grains and imperfect crystals. The mineral next in abundance is quartz, which seems to be of two periods. The remaining secondary metamorphic minerals observed are calcite, magnetite (or ilmenite) and epidote, which are present only in small amount. The latest mineral in general is quartz. After the rock had been severely crushed and fractured the cracks and openings became filled with quartz, which occurs in macroscopic and microscopic lenses, irregular bodies, and veins. The smaller veins have in general a direction roughly parallel with the ore bed and connect variously with the larger bodies or lenses, in places forming a closely woven reticulating meshwork, with garnet filling the interspaces.

At the tunnel level a tabular vein or seam of copper ore with quartz gangue inclines eastward at an angle of about 40° and is opened on the incline by what is known as the Molybdenite winze. In the vicinity of the level the vein is only a few inches in width, but with it, on either side, is associated from 1 to 3 feet or more of the above-described mineralized limestone, which contains chalcopyrite, pyrite, coarse calcite, and quartz, and which is a low-grade copper ore.

In the incline at a depth of 35 or 40 feet below the level, however, conditions change. Here molybdenite occurs in both the vein and the inclosing rock, mingled with the chalcopyrite and pyrite. In the next 8 or 10 feet below the dip flattens somewhat, the chalcopyrite and pyrite decrease greatly, and there is a more than corresponding increase in the amount of molybdenite, so that the deposit is there a relatively pure molybdenite ore, and seems to constitute a body or ore bed at least 3 or 4 and probably 6 or 7 feet in thickness. Owing to the presence of water in the shaft sunk at the end of the incline, examination could not be made across the entire bed. So far as observed there seemed to be no detrimental intermingling of chalcopyrite.

The molybdenite occurs in lenses, irregular bodies or bunches, and crystal aggregates embedded in and associated with both the rock and the quartz. It is mostly fine-grained, but some of the crystal plates range up to one-half inch or more in maximum diameter.

Bodies of the molybdenite inclosed in the middle of some of the quartz veins indicate that deposition of this ore probably continued after that of the quartz, with which the molybdenite seems to be in the main contemporaneous. Like the quartz, it was probably deposited by thermal solutions that accompanied or followed the intrusion of the aplite dikes or granite porphyry.

A considerable amount of molybdenite can be seen on a large dump of low-grade copper ore at the entrance to the mine, and a smaller pile of 8 or 10 tons of molybdenite ore is reported to average 6½ per cent of molybdenum. At the time of visit in 1909 the company was planning to mine the deposit commercially and expected to produce ore with a very much higher percentage of molybdenum.

RIDLEY MINE.

The Ridley mine, owned and worked for copper by C. B. Ridley, of Helvetia, is located in the foothills a mile southwest of Helvetia at an elevation of about 4,060 feet. The topography in this vicinity is gentle. The country rock is the pre-Cambrian (?) granite and it is freely intruded by dikes and masses of aplite which, as shown by the croppings to the north of the mine, are associated with the vein. The mine is situated on a tabular quartz vein that contains the ore and dips about 50° E. It is developed by an incline on the vein to a depth of 150 feet and contains short drifts on two levels, one of which is near the bottom of the shaft and the other 55 feet above it. The vein varies in thickness from 2 to 5 feet and averages about 4 feet. Some of the quartz is drusy. The better ore occurs in the lower part of the mine. Here it is mostly contained in a 10 to 18 inch pay streak on the hanging-wall side of the vein. It consists of alternating bands of quartz and sulphides—pyrite, chalcopyrite, argentiferous galena, and sphalerite—and is said to run about 6½ per cent in copper and 30 ounces in silver and $1.50 in gold to the ton.

In the south drift on the lower level a little molybdenite is scattered through the ore, and in the sump at water level, between the pay streak and the granite hanging wall, occurs a band from one-eighth inch to 4 inches in width, composed of sericitic mica, quartz, pyrite, and fine-grained molybdenite. In places this material seems to constitute a good molybdenum ore. Its concentration, however, may be difficult owing to its mixture with mica.

MADERA CANYON.

Madera Canyon drains the northwestern part of the Old Baldy section of the Santa Rita Mountains, about 10 miles south-southwest of Helvetia and 35 miles south of Tucson. In the foothill part of its course, where the creek and wagon road cross the Pima-Santa Cruz county line, a short distance above White House, as indicated on the accompanying map (fig. 12), occur a group of molybdenite prospects commonly known as the McCleary prospects, from the name of the owner. They range from about 4,500 to 5,000 feet in elevation and trend nearly north and south along the creek, extending half a mile on either side of the county line. The deposits probably have a much wider extent in an east-west direction, for the prospects here described have only accidentally been brought to light by the erosion of the creek across a seemingly small portion of the area.

In this part of its course the creek, a fine, clear mountain stream, about 2 feet wide by 3 inches in depth, flows in a trench but 5 to 15 feet deep. The topography is gentle and the prospects are all easily accessible.

The country rock is pre-Cambrian (?) granite. It has been fractured by dynamic disturbances, and along the more prominent of the resulting joints and fault fissures occur quartz veins containing the prospects. These veins vary from 1 foot to 12 feet or more in width and are mostly compound veins or stockworks. They are in the main associated with intrusive aplite or allied dikes, with which, as at Helvetia, the deposits are probably genetically connected.

The most important exposures, as shown in prospect shafts and tunnels, will be described in downstream order from south to north.

The most southerly of the prospect holes is situated on the west side of the creek at an elevation of 4,990 feet. It is on a small, somewhat iron-stained quartz vein that carries pyrite, chalcopyrite, and flaky molybdenite and dips 70° N. A 20-foot dike of aplitic granite forms the hanging wall.

Just south of the road forks, in the creek bank, at an elevation of 4,765 feet, in a fine-grained phase of the granite, a 4-foot vein of iron-stained honeycombed quartz dipping steeply to the north is opened by a shaft which was filled with water at the time of visit, but is reported to be 40 feet deep. On the surface the vein exposes a little flaky molybdenite and a very minor amount of pyrite and chalcopyrite.

On the east side of the creek, about 200 feet from the road, at an elevation of 4,675 feet, the granite is traversed by a stockwork several feet in width, composed mainly of massive iron-stained dark smoky quartz veins. It strikes N. 60° E. and the dip is vertical or steep to the north. The quartz is in part drusy or comby. It is concentrated along the north or hanging-wall side of the fissures, where it is from 6 inches to 2 feet in width and contains a little pyrite and a less amount of chalcopyrite. Associated in part with the pyrite and chalcopyrite and occurring also independently of these minerals, exposed at many places on the joint planes, are flakes of molybdenite that are locally concentrated in masses one-fourth inch thick and covering an area of about a square inch. Flaky aggregates and small bodies of pure molybdenite also occur in the druses and otherwise inclosed in the quartz, as at Helvetia. Associated with the larger masses of the molybdenite and also with limonite on the joints near the surface is a soft yellowish earthy material which looks like clay, but which on examination was found to be ferrous iron sulphate. At the mouth of the 10-foot tunnel driven on this prospect, dipping steeply to the southeast, occurs what seems to be a dike of fine-grained aplitic granite, with which the molybdenite is probably genetically connected.

The most northerly and apparently the most important prospect of the group is on the east side of the creek, at an elevation of 4,560 feet. Here in the granite is exposed a stockwork of quartz veinlets 3 to 7 feet wide. It dips about 60° NNW. and is traceable for a distance of 1,500 feet eastward from the opening. The granite between the veinlets is very much altered. It is soft, is of a yellowish-red color, due seemingly to iron staining, and contains pyrite crystals and flakes of molybdenite. The quartz forming the veinlets of the stockwork is smoky and coated with limonite and a little molybdenite. Some walls of open fissures are coated or glazed with a black sinter-like substance, which is mostly silica but contains manganese and molybdenum. It is particularly abundant on the south or foot wall.

PROVIDENCIA CANYON.

GENERAL DESCRIPTION.

Providencia Canyon heads about 2 miles northwest of Washington, in the southern part of the range, drains a considerable portion of the western slope, and joins the Santa Cruz 6 miles northeast of Nogales. The molybdenite prospects here described are in the foothill portion of its course, in the general region of the Golden Rose and Buena Vista mines, 10 miles north-northeast of Nogales, 5 miles west of Washington, and about 5 miles north of the international boundary, at elevations between 4,200 and 5,000 feet.

The topography is rough, being of the type formed from an area of igneous rocks scored by canyons and gulches in an arid climate, but the canyons or washes form avenues of approach to the mines.

The country rock is pre-Cambrian (?) granite, faulted and intruded by dikes and masses of quartz diorite generally, with granite porphyry occurring near by. As in Madera Canyon, it has suffered considerable dynamic disturbance, and the resulting fault fissures locally contain mineral-bearing quartz veins or lodes. The granite also locally contains metallic minerals in considerable amount.

In the northwestern part of the triangular area bounded by Sycamore Canyon on the south and east and Providencia Canyon on the northwest, just southeast across Providencia Canyon from the Golden Rose mine, the granite is uniformly impregnated with evenly disseminated small macroscopic crystals, aggregates or masses, and grains of chalcopyrite and pyrite, and contains sparingly molybdenite, having much the same habit as the other minerals. These mineralogical conditions are very constant throughout the mile or more of the northwest slope of the mountain examined opposite the Golden Rose mine, where in prospecting for copper the ground has been opened at intervals by shafts and tunnels from 10 to 80 feet in depth, and the same conditions are reported to prevail over most of the area above described, which occupies 2 square miles or more and rises 800 feet above the canyon.

From cursory examination these minerals seem in all respects to be primary constituents of the granite, but as such occurrence is unusual, decision on this point must await further examination.

Hess,[a] from investigations of the same minerals in other fields, concludes that the minerals are probably not primary and that the molybdenite in the places he cited was deposited possibly by a gaseous solution that had greater power than a liquid solution to penetrate the dense granite.

BUENA VISTA MINE.

The Buena Vista mine, owned by the Banco del Oro Mining Company, of Magdalena, Sonora, Mexico, is located about three-fourths mile southeast of the Golden Rose mine and the locality above described. It is in the pre-Cambrian (?) granite, on a fault or shear zone, with intrusive quartz diorite outcropping on the ground and granite porphyry occurring near by.

The zone comprises half a dozen or more fault fissure veins and associated lodes of more or less mineralized crushed rock, all of which dip about 60° SSE. The veins range from 6 inches to more than 6 feet in width. The two most important are about 100 feet apart. The vein filling is quartz with here and there associated calcite. The mine contains about 2,000 feet of work. It is developed principally by three tunnels on suitably spaced levels between approximately 4,700 and 5,000 feet in elevation. Two of the tunnels are drifts on the main vein. The other is a crosscut which opens a parallel vein.

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[a] Hess, F. L., Some molybdenum deposits of Maine, Utah, and California: Bull. U. S. Geol. Survey No. 340, 1908, pp. 231-239.

In the lower drift, which is 415 feet in length, the main vein contains about 5 inches of white quartz and calcite that carries chalcopyrite, pyrite, and a little flaky molybdenite. The ore is separated from both walls by gouge. In the face of the crosscut tunnel, which is 45 feet above the lower tunnel, is a 4-foot zone of crushed granite and quartz carrying pyrite, chalcopyrite, and a little flaky molybdenite.

DUQUESNE.

The well-known mining camp of Duquesne, south of Washington, lies on the east slope of the Patagonia Mountains, about 2 miles north of the international boundary and about 15 miles east-northeast of Nogales. At the southwestern border of the camp, about one-fourth mile west of the Belmont mine, on ground owned by Captain O'Connor, of Duquesne, occurs ore which shows galena, chalcopyrite, pyrite, and a little molybdenite, associated with drusy quartz. The deposit is in the country-rock granite just west of the contact of this rock with limestone. The granite is intruded or cut by masses of granite porphyry. Both rocks are much shattered and are traversed in all directions by a large number of the drusy quartz veins. The property is developed by several shafts, but these could not be entered at the time of visit, as they were full of water.

SAN ANTONIO CANYON.

Molybdenite is contained in two openings, the Benton mine and the Line Boy prospect, near the international boundary, in San Antonio Canyon, at the east foot of the Patagonia Mountains, about 2 miles south of Duquesne and 15 miles east of Nogales. The more important of these is the Benton mine.

BENTON MINE.

The Benton mine, owned by Dennis Coughlin and partners, of Duquesne, is situated about three-fourths mile northeast of post 113 of the international boundary line, on open ground, at an elevation of about 5,200 feet. It is developed principally by a 155-foot tunnel. The country rock is granite, intruded by granite porphyry and aplitic granite. The granite porphyry contains the values of the mine, which consist of low-grade copper and gold ore. The ore occurs chiefly in a dike of this rock 60 feet wide, which is impregnated with pyrite, chalcopyrite, and a little flaky molybdenite. Its contact with the granite is marked by a sericitic zone a few feet in width.

LINE BOY PROSPECT.

The Line Boy prospect, owned by Captain O'Connor, of Duquesne, is located just north of post 113 of the international boundary, about three-fourths mile southwest of the Benton mine, at an elevation of about 5,400 feet. It is developed to a depth of 80 feet by three shafts and a tunnel.

The country rock is gray granite, intruded by a north-south dike of granite porphyry 300 feet in width. The ore deposits are contained in the granite, which near the dike is impregnated with pyrite, chalcopyrite, molybdenite, and a little bornite. The metallic minerals are particularly abundant along the contact of the two rocks and are concentrated in joint planes and fissures, locally with a little associated quartz. In one place occurs a 3-foot band of fine-grained, friable, and relatively pure specularite.

The molybdenite occurs also unassociated with the other sulphides, in the form of comparatively pure lumps or crystals, in places one-eighth of an inch thick and more than half an inch in diameter, in a coarse siliceous, sericitic phase of the granite. It also, with quartz in about equal amount, forms veinlets of considerable continuity that traverse less acidic portions of the granite and range from microscopic width to one-sixteenth inch. It is also present in small amount in microscopic to very small macroscopic veinlets or seams traversing a dense phase of the granite. The veinlets are parallel, ten or twelve being contained in a single thin section made for microscopic study. They contain and are associated with microscopic druses.

ORIGIN OF THE DEPOSITS.

At all the localities here described the molybdenite, whether found in veins, as impregnations in the rock, or in other forms, occurs in granite or in quartz veins cutting the granite. All the deposits, besides being intimately associated with considerable quartz, are also more or less intimately associated with granitic intrusive rocks—aplite, granite porphyry, and allied acidic rocks. From the constancy of these conditions it seems probable that some genetic relation exists between the deposits and the intrusive rocks, and that the deposits were probably formed by precipitation from thermal solutions whose circulation accompanied or followed the intrusions.

FUTURE PROSPECTS OF THE DEPOSITS.

The only one of the above-described localities at which molybdenite seems to be present in workable quantities is at Helvetia, notably in the Leader mine. However, as all the deposits occur under geologic conditions favorable for molybdenite and are still in the prospect stage, it is possible that with development some others may prove to be of economic value. At the time of visit the Madera Canyon prospects were being exploited for molybdenite. An important point in the selection of deposits for development is the absence of chalcopyrite, for this mineral is difficult to separate from molybdenite and thus reduces its market value.

GENERAL OCCURRENCE OF MOLYBDENITE.

According to Crook,[a] the molybdenite at fifty or more localities in different parts of the world which have been described occurs in a great variety of rocks, including practically all the main groups, but its occurrence with granite is by far the most usual and typical. Hillebrand[b] also states that molybdenite accompanies the more acidic rocks and is a well-known constituent of some granites.

According to Crook, "the association with sulphides and oxides is that most characteristic of the occurrence of molybdenite in quantity in veins." In small quantities the mineral is not at all uncommon in the fissure veins of the Cordilleran States. The deposit at Crown Point, Wash.,[c] economically one of the most important in the United States, is a quartz vein in which molybdenite occurs in association with chalcopyrite.

USES AND PRODUCTION OF MOLYBDENITE.

Molybdenite is important as the main source of molybdenum, whose chief use in recent years is that of an alloy in the manufacture of steel. Other uses[d] of molybdenum in its different compounds are, as ammonium molybdate, to determine phosphorus in iron; as fire-proofing material; as a germicide; as a disinfectant; as sodium molybdate, to color pottery and porcelain blue and to dye silks and woolens; as molybdenum tannate, to color leather; and, as "molybdenum indigo," to color india rubber.

According to Hess,[e] the price of molybdenum ordinarily ranges between 20 and 30 cents a pound for material carrying 92 per cent of molybdenum sulphide. The production of molybdenite ore in the United States is small, being in ordinary years less than 50 tons carrying 92 per cent of molybdenum sulphide.

[a] Crook, A. R., Molybdenite at Crown Point, Wash.: Bull. Geol. Soc. America, vol. 15, 1904, pp. 283-288.

[b] Hillebrand, W. F., Distribution and quantitative occurrence of vanadium and molybdenum in rocks of the United States: Bull. U. S. Geol. Survey No. 167, 1900, p. 53.

[c] Landes, Henry, Ann. Rept. Washington Geol. Survey, 1901, vol. 1, pp. 41, 92, 93. Crook, A. R., Bull. Geol. Soc. America, vol. 15, 1904, p. 285. Pratt, J. H., Mineral Resources U. S., 1899 to 1902, U. S. Geol. Survey.

[d] Hess, F. L., Molybdenum: Mineral Resources U. S., for 1908, pt. 1, 1909, pp. 745-747.

[e] Op. cit., p. 747.

NOTE ON THE OCCURRENCE OF TUNGSTEN MINERALS NEAR CALABASAS, ARIZONA.

By J. M. Hill.

In the latter part of June, 1909, the writer made a short visit to the tungsten deposits about 3 miles south and a little east of Calabasas, Ariz., a station on the Nogales branch of the Southern Pacific Railroad, 10 miles north of Nogales. Information on this occurrence was also obtained from Messrs. Taylor, Peck, and Reagan, of Nogales, the two latter men owning claims in the vicinity.

The presence of wolframite was first noted about 1906, and a few prospect holes sunk at that time led to mild excitement. Little work has been done on the deposits. The deepest shafts are about 30 feet and the greater number are less than 10 feet in depth. Mr. Reagan has shipped about 1,000 pounds of ore which he states assayed more than 50 per cent tungstic acid, and about 400 pounds of ore of the same grade is still on the ground, together with several hundred pounds of lower-grade material.

The low north end of the tongue of land between Santa Cruz River and Nogales Wash is underlain by a very coarse, in many places porphyritic, granodiorite of light-gray color, that weathers to a flesh pink or dull red. In this rock are pink orthoclase crystals up to half an inch in diameter; the striations on plagioclase are plainly visible, and blebs of quartz and some dark micaceous mineral can be distinguished.

The granodiorite is cut by intrusive rocks of two types. One of small extent and of little importance so far as the ore deposits are concerned is a fine granular rock composed of orthoclase, quartz, some plagioclase (possibly andesine), and an insignificant amount of biotite.

The dikes that are most closely associated with the wolframite deposits are of the same type, but apparently of two ages of intrusion, possibly very close together. One set strikes N. 75° W. and dips at rather high angles to the north. The other and later system strikes N. 25° W. and is vertical or has a very steep dip to the west.

None of these dikes are over 6 feet across and most of them are between 2 and 4 feet. Some of them are traceable for 1,500 to 2,000 feet, but the greater number are shorter. The whole tongue is a grill of dikes in which those trending east and west are the more numerous. At one place four dikes, each about 2 feet wide, were seen within 100 feet, all striking N. 75° W. These were crossed by two north-south dikes.

The rock is a greenish-black, dense, fine-grained lamprophyre. Under the microscope it appears holocrystalline with trachytic texture. The most important constituents are an undeterminable plagioclase with index of refraction probably less than Canada balsam, long needle-like altered greenish crystals of hornblende, and a minor amount of quartz. The rock is largely altered to chlorite and a little epidote and contains some hematite, probably derived from magnetite, which is fairly abundant in the rock. It is cut by veinlets of calcite. Some phases are rather coarsely porphyritic, and in these the weathered surfaces are pitted, the casts being coated with iron oxide or filled with calcite.

The contacts of these dikes with the granodiorite are extremely sharp. The latter is apparently little changed except for a fraction of an inch. Along this belt, though the original constituents of the granodiorite are still visible, there is also a great deal of epidote and a chloritic mineral developed from both feldspars and ferromagnesian minerals. For one-fourth of an inch from the contact the intrusive rock is very dense, fine grained, and black; inside of this there is a belt of varying width, dependent on the size of the dike, that is much epidotized and chloritized; and in the center the rock is unaltered.

The deposits are veins showing beautiful comb structure, and in places repeated bands of quartz and wolframite. The usual order from the wall inward is quartz, wolframite. Here and there this order is reversed, and it may be that the deposition was more or less simultaneous, as wolframite crystals are seen in some of the quartz layers, and vice versa. Postmineral movement is shown by the gouge-covered wall, but the veins were not much crushed by this disturbance. In a number of places the quartz is cemented to the wall by a thin layer of greenish siliceous material, which is very dense, like a silicified shale, and may be the intrusive rock that has been altered by the solutions which formed the veins.

The principal gangue mineral is quartz, but there are some small crystals of calcite. The walls and gouge are in many places iron stained.

The only metallic minerals are wolframite, a dark reddish-black heavy mineral with metallic luster and brownish streak, and a very minor amount of scheelite. The wolframite is in part fairly well crystallized, but mostly rather massive. In the crystallized form, in the larger veins, the crystals have apparently grown into an open space that has later filled with white vitreous quartz. The wolframite near the surface is partly altered to iron oxide, which shows the form of the original crystal.

Most of the veins are under 10 inches in width, though some up to 2 feet were noted. The latter, however, are largely quartz. The veins occur both in the dikes and in granite near the dikes, and apparently the association between the wolframite and the intrusive rocks is very close.

Wolframite, however, is not found in all the veins nor in all parts of a single vein. It seems to lie in pockets in the larger quartz veins and to be more concentrated where these pinch. In the smaller veins the deposition of wolframite was apparently more general, as bands about one-eighth of an inch thick are fairly continuous along some of these veins. No large pockets were seen, the largest being about 4 by 3 feet along a 6-inch vein.

At the Reagan property, one-fourth of a mile east of the railroad and 2½ miles south-southeast of Calabasas, there are several open cuts and two shafts on a group of three veins. The country rock is granodiorite, very much altered and weathered. This is cut by two dikes of the dark rock described above, striking N. 75° W. The veins are apparently later than the dikes, which they offset a few feet. These veins all strike N. 25° W. and stand almost vertical. The central one is 30 feet west of the east vein and 60 feet east of the west vein.

The two outside veins are small and well banded and contain minor amounts of wolframite. The "tungsten" ore is usually next the wall rock, and the vein has a central band of comby quartz. The central vein varies from 1 to 2 feet in width and consists largely of quartz in which are pockets and stringers of wolframite. The deposition seems to have been repeated, as the banding from the wall inward is quartz (0.2 inch), wolframite (0.3 inch), quartz (0.25 inch), wolframite (0.1 inch), and quartz. The banding is not at all regular, however, wolframite locally filling the entire space inside of the first quartz bands. Scheelite occurs as minute crystals in the quartz near the bands of wolframite.

A 30-foot shaft at the Reagan property could not be entered, so conditions at that depth could not be studied. The veins as seen, however, to depths of 15 feet showed a slight pinching and rather less wolframite at the bottom. From the few prospects visited no generalization can be attempted as to the probabilities of ore at greater depth.

The deposits as a whole do not seem particularly encouraging. There are a large number of veins, but apparently most of them are nearly or quite barren. In the others wolframite is present in such small quantities and the pockets are so widely scattered as to hardly pay for mining.

SOME CHROMITE DEPOSITS IN WESTERN AND CENTRAL CALIFORNIA.

By E. C. Harder

INTRODUCTION.

Chromite is widely distributed through areas of serpentine and associated basic rocks in various parts of the United States. Such rocks are found at a few localities in the old crystalline region east of the Appalachian Mountains from New England to Georgia, at various points in the Rocky Mountains, throughout the extent of the Sierra Nevada and Coast Range in California, and at a few points in the Cascade Mountains. Chromite, being one of the accessory minerals in serpentine rock, probably occurs in a disseminated condition in all these regions, but its concentration is very local. Deposits are found in Massachusetts, Pennsylvania, Maryland, North Carolina, Wyoming, and California.

Chromite is the only commercial ore of chromium. Theoretically its composition is $FeO.Cr_2O_3$, with 32 per cent of ferrous oxide (FeO) and 68 per cent of chromic oxide (Cr_2O_3). Practically, however, the content of chromic oxide varies down to 10 per cent in the ores, though generally ranging between 40 and 60 per cent, and the ferrous oxide content varies from 10 to 50 per cent. Alumina and magnesia are almost invariably present, and in places they form a considerable proportion of the ore, alumina being present in quantities varying up to 30 per cent and magnesia in quantities varying up to 20 per cent. Ferric oxide is commonly present in small quantities. Alumina and ferric oxide replace chromic oxide and magnesia replaces ferrous oxide.

Chromite deposits are of two kinds—(1) pockets or lenses in serpentine or associated basic rocks, formed during the intrusion and cooling of the original magma by the segregation of chromite particles, and (2) chrome sands along watercourses, formed by the mechanical concentration of chromite particles derived from the weathering of serpentine, in which they occurred as disseminated granules or in pockets and lenses. Nearly all the deposits worked commercially have been of the first type.

The chromite deposits of Pennsylvania and Maryland were operated at intervals between 1827 and 1880, but have since yielded little or no ore. Chrome ore was discovered in California in the early seventies, but there was no production until 1880. Since then, however, nearly all the chromite produced in the United States has come from this State. Wyoming became a producer in 1908. No production has been recorded from North Carolina or Massachusetts, but the deposits have been occasionally exploited.

The chief producing counties in California have been San Luis Obispo, Shasta, Alameda, Del Norte, Placer, Glenn, and Tehama; minor quantities have been produced in Napa, Sonoma, and Calaveras counties. A total production of about 37,700 long tons has been reported from California from 1880 to 1908, inclusive. At the present time the only chrome deposits in California which are being worked are those of Shasta County. Deposits in San Luis Obispo, Alameda, Placer, and Calaveras counties were visited by the writer during a brief reconnaissance trip through western and central California during the fall of 1909.

DESCRIPTION OF DEPOSITS.

SAN LUIS OBISPO DISTRICT.

GENERAL DESCRIPTION.

The San Luis Obispo district is located on the coast of California about halfway between San Diego and San Francisco. It is on the west slope of the Coast Range, which in this district is represented by the Santa Lucia Range in the northeastern part and the San Luis Range or Los Osos Mountains in the southwestern part. The direction of the ranges is northwest and southeast, the Los Osos Mountains being near the coast and separated from the Santa Lucia Range by the Los Osos and San Luis valleys. Los Osos Valley runs into the ocean on the northwest at Morro Bay, and thence northward the Santa Lucia Range follows the coast. Northeast of the Santa Lucia Range is the Santa Margarita Valley, and beyond this are other parallel ranges.

The oldest rock formation in the district is granite of pre-Jurassic age, forming a large mountainous area northeast of the Santa Margarita Valley.[a] Next in age is the Franciscan formation (Jurassic), which consists of sandstone, conglomerate, shale, and amphibolite schist, and contains numerous jasper lenses. In the San Luis folio this is called the "San Luis" formation, but that local name has now been abandoned in favor of the older and better-known term Franciscan. It is intruded by basalt and diabase of slightly later age. This series of rocks is very irregular in its distribution. Above the

[a] Fairbanks, H. W., San Luis folio (No. 101), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

MAP SHOWING THE DISTRIBUTION OF SERPENTINE AREAS AND CHROMITE MINES IN THE SAN LUIS OBISPO DISTRICT, CALIFORNIA.

Franciscan formation is the Lower Cretaceous Knoxville formation, consisting of dark shale and sandstone. This formation was called 'Toro" formation in the San Luis folio, but that local name has also now been abandoned in favor of the older and better-known term Knoxville. The Franciscan formation, and to a less extent the Knoxville formation, are intruded by granophyre, serpentine, and diabase. The serpentine areas are irregular and of varying size and occur throughout the Santa Lucia Range and in the Los Osos Mountains. They contain all the chromite deposits of the district. Younger sediments ranging from late Cretaceous to Pleistocene in age and Miocene intrusive rocks, consisting of andesite, rhyolite, and diabase, occur in various parts of the district.

Indications of chrome ore can be seen locally in the serpentine areas along the Santa Lucia Range and Los Osos Mountains and elsewhere within the district and they continue northwestward beyond the district. (See Pl. I.) The principal deposits, however, occur on the southwest slope of the Santa Lucia Range from 5 to 20 miles north and northwest of San Luis Obispo and in the Los Osos Mountains about 3 or 4 miles southwest of that town. There are a few deposits in the northeast slope of the Santa Lucia Range about 4 miles east-southeast of Santa Margarita[a] and on the west slope of Pine Mountain,[b] in the northwestern part of San Luis Obispo County but outside of the district proper.

In general the ores occur in lenses or pockets, of which many are rather irregular but nearly all are more elongated in two dimensions than in the third. They vary in width from a foot or less to 15 or 20 feet and in length up to several hundred feet. The greatest depth reached in the excavations observed by the writer was about 30 feet. In most places small branches run off from the main lens or pocket at varying though generally small angles. The main lens narrows and widens somewhat irregularly. Locally lenses are grouped along certain zones which may extend for a distance of half a mile or even a mile. As shown later, such zones generally extend along contacts. On the other hand, single deposits may be widely scattered.

The main lenses or pockets of chrome ore are made up of smaller bunches and veins of ore separated by serpentine which is but slightly impregnated with chromite. The wall-rock serpentine adjacent to the deposit is also slightly impregnated with chromite, which becomes more abundant as the deposit is approached. Similarly the bunches of chromite generally contain varying amounts of serpentine, though in places there are small masses perhaps 5 or 6 inches in diameter of almost pure chromite. In places, as in the Los Osos Mountains, the serpentine is badly weathered near the surface, having in consequence

[a] Fairbanks, H. W., op. cit.

[b] Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 269.

a cellular structure due to unequal solution. Some portions of the rock are much decomposed and sandy; others are quite fresh. As a rule the rock is least decomposed around specks and bunches of chromite. The chromite is more resistant to erosion than the serpentine, and therefore where present is more or less concentrated near the surface.

The chromite of the district is of the glossy black crystalline variety and is generally found in small rounded granules in the serpentine. These granules vary from one-fiftieth of an inch or less to one-third of an inch in diameter and occur at varying distances apart, after the nature of phenocrysts in a porphyritic rock. Where the granules are small the mineral is finely crystalline; where they are larger it is more coarsely crystalline. In spots the particles are so close together that little or no serpentine remains, and in such places the ore is very coarsely crystalline.

Many of the deposits occur in the serpentine near the contact of older rocks into which the serpentine has been intruded. Such rocks may surround serpentine areas or may occur as masses within the serpentine. Hence deposits may be found extending around the borders of serpentine areas or may occur near included older rock masses within serpentine areas. Other deposits apparently have no such connection with older rocks and are scattered through the serpentine. In many of the areas the included rock masses are fine-grained biotite schist, and locally chromite deposits are found along their contacts.

MORRO CREEK.

Several chrome deposits that have been operated lie in a serpentine area crossing Morro Creek in a northwest-southeast direction, just below its junction with East Fork about 12 miles northeast of San Luis Obispo. Ore is found at several localities north of Morro Creek, but the most important deposits are to the south. These are reached by way of a road up Morro Creek to its junction with East Fork and thence by a trail into the hills. The deposits are on the southwest slope of the Santa Lucia Range a short distance below the summit. The hills are covered with a thick growth of chaparral and chamiso brush, with here and there clumps of manzanita, scrub oak, and yucca. Trees are rare in this part of the range except in the valleys, where live oak, white oak, and a few digger pine occur.

The principal workings are a mile south of Morro Creek, to the right of the trail. They consist of three irregular trenches arranged end to end in a direction about N. 45° W. The workings are 150 feet or more long, from a few feet to 30 or 40 feet deep, and up to 20 feet wide. The trenches follow a series of chromite lenses and pockets extending along the north contact of a lenticular mass of fine-grained biotite schist which is from 15 to 25 feet wide and is traceable throughout the length of the workings. At a few places the biotite schist touches the south wall of the trenches, but in general it is several feet away.

The chromite occurs in a nearly vertical zone from a foot or less to possibly 10 or 15 feet in width and extending at least for the length and depth of the trenches. (See fig. 13.) At one or two places the deposits pinch out for a few feet, so that the ore zone probably consists of several lenticular pockets arranged end to end. Smaller pockets lie in the wall rock alongside of the main series and are probably connected with them by stringers. Considerable fissuring has taken place along the chromite zone, as shown by numerous slickensided surfaces. The chromite as well as the serpentine has taken part in this movement, showing that the ore was formed previous to the fissuring. This fissuring is characteristic of serpentine wherever it is found as an alteration of basic olivine rocks, such as peridotite and gabbro, and is supposed to be due to pressure accompanying the increase in volume which results from this alteration. It follows, therefore, that the chromite was formed before the alteration to serpentine took place and was probably part of the original gabbro or peridotite intrusion.

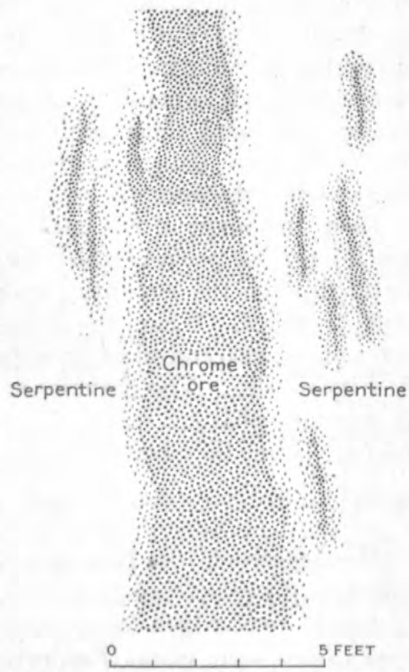

FIGURE 13.—Vertical section through a lenticular pocket of chrome ore south of Morro Creek, 12 miles northeast of San Luis Obispo, Cal.

There is no sharp line between the ore and the serpentine. Chromite occurs in small specks in apparently barren wall rock, and close to the deposits it is disseminated rather abundantly. Serpentine also occurs in all the chromite pockets in varying abundance, depending on the closeness of spacing of the chromite particles.

Only a small quantity of ore remains in sight on the walls of the trenches, though about 10 or 15 tons of it lies on the dump. The floors of the trenches were covered with débris, so that it was impossible to determine whether or not the deposits continue below the present workings.

There is another group of less extensive workings consisting of open cuts about a mile southeast of the deposits described above and on the same slope. Others are found elsewhere in the same area, but were not examined.

PENNINGTON CREEK.

In the large serpentine area east of the head of Pennington Creek there are numerous pockets of chrome ore. Most of them are small, but they occur abundantly scattered through the area. They may be reached by way of a road going up to the head of Pennington Creek or by way of a road running into the mountains west of the horseshoe curve on the Southern Pacific Railroad.

Most of the workings are on an upland flat a short distance southwest of the main summit of the Santa Lucia Range, and on the sides of stream valleys cut into it. Very little ore is now in sight, though undoubtedly numerous deposits are undiscovered. The located deposits are all apparently exhausted. They were worked by small surface cuts and short tunnels, in but few of which was any ore visible in place, though at one tunnel about 10 tons of low-grade ore remained on the dump.

From the shape of the workings it appears that the ore occurs in small irregular pockets which locally seem to be scattered promiscuously through the serpentine area, and elsewhere are arranged along definite zones. Where ore is still visible it is of low grade, being intermixed with considerable serpentine, in which it occurs in granules of varying size. The granules are largest where the least serpentine is present—that is, where they are closest together—and as they become larger they become more coarsely crystalline.

MINE HILL.

The deposits in the Los Osos Mountains are on Mine Hill, about 4 miles southwest of San Luis Obispo. They are best reached by way of an old road which leaves the main highway at the Jasper place, near the Pacific Coast Railway. The workings consist of several groups of open cuts and tunnels scattered along the top of a brushy ridge for a mile or more.

The principal group of workings is about a mile northwest of the Jasper place. It consists of a tunnel and three or four large open cuts. The ore occurs in small specks and bunches disseminated through weathered and decomposed serpentine. Little or no pure chromite occurs, all the ore carrying a varying quantity of serpentine. Near the surface the serpentine is cellular, as a result of solution, the part remaining being that around chromite particles. A short distance below the surface the serpentine is gray, soft, and sandy between the ore specks, while that around the ore is compact and dark green. Where no ore is present the serpentine is all soft and grayish.

The other workings scattered over the ridge are chiefly small open cuts in local groups. The occurrence of the ore here is the same as described above. The serpentine everywhere seems to be soft and decomposed.

COMMERCIAL IMPORTANCE.

Large quantities of chromite have been shipped from the San Luis Obispo district, though the mines have been idle for many years. Most of the deposits operated are exhausted, but there are undoubtedly many others to be discovered. Prospecting is extremely difficult, as the serpentine areas for the most part are thickly covered with chamiso, chaparral, and brush oak, which not only conceal the soil but are penetrated with the greatest difficulty by prospectors. The activity was greatest about twenty-five or thirty years ago, and in 1890 it was estimated[a] that 11,000 tons had been shipped from the district. A small concentrating mill was once operated in San Luis Obispo, but is now out of use.

MENDENHALL CHROME MINES, LIVERMORE.

The Mendenhall chrome mines consist of several groups of workings on Cedar Mountain, Alameda County, about 12 miles southeast of Livermore. The deposits are best reached by way of the Mendenhall Springs road along the southwest slope of Arroyo Mocho. There are two groups of workings, several hundred yards apart, just west of the crest of the ridge extending northward from the summit of Cedar Mountain. Both consist of several open cuts and tunnels. A magnesite mine is near the chrome workings.

Cedar Mountain consists largely of serpentine which is intrusive into sandstone and shale of the Franciscan formation (Jurassic), the latter forming most of the eastern slope of the hill. The ore occurs in irregular lenticular pockets and stringers in more or less decomposed serpentine. Where the serpentine is much decomposed it is soft and broken and has a brown stain. The chrome ore that occurs in this rock is generally soft and friable and of a dull grayish-black color, but that in the fresh serpentine is glossy black in color and contains very little intermixed serpentine. Some masses of fairly compact ore are found within pockets of soft ore, as if they were not yet thoroughly disintegrated. Pockets of soft ore are homogeneous—that is, there are no particles of serpentine visible within the mass—and the contact with the decomposed serpentine surrounding them is very gradual. On the other hand, the contact between the fresh serpentine and chromite grains is sharp, and small particles of serpentine are visible throughout the chrome masses. However, the percentage of the serpentine in this ore is very much smaller than that in the average

[a] Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 269.

ore from the San Luis Obispo district. Bright-green chrome ocher, a clay stained with chromic oxide, occurs at many places in the soft decomposed ore and along cracks in the fresh ore.

The workings at each of the localities cover an area about 100 by 50 or 60 feet. Single pockets are generally less than 10 feet long. Very little ore is in sight in the workings, and that is of low grade. Some low-grade ore also remains on the dumps. More than 3,000 tons of chrome ore is said to have been mined here, but operations stopped many years ago, probably because of the exhaustion of high-grade ore.

CHROMITE DEPOSITS NEAR VALLEY SPRINGS.

GENERAL DESCRIPTION.

The chromite deposits near Valley Springs occur in the central portion of the narrow belt of discontinuous serpentine areas extending in a northwest-southeast direction through southwestern Eldorado, Amador, Calaveras, and Tuolumne counties, along the lower foothill region of the Sierra Nevada. The portion of the belt near Valley Springs [a] is parallel to and just west of the Mother Lode district. This central portion is for the most part not more than a few miles wide, but to the northwest and southeast it widens and branches.

The serpentine is older than late Cretaceous, being intrusive into a variety of Carboniferous and Jurassic rocks which occur with it in parallel bands. The basal formation consists of Carboniferous (Calaveras) quartzites, argillites, and schists, which are intruded by amphibolite schists, diabase, and porphyrite. With them are associated slates of Jurassic age (Mariposa). This entire series has been compressed and complexly folded and faulted, the disturbances producing their schistosity and their distribution in northwest-southeast bands. They are locally covered by later Tertiary sediments and beds of fragmental rhyolite and andesite and are intruded by late Cretaceous igneous rocks of various types.

Chromite deposits occur at intervals along the serpentine belt in this district and continue to the north and south. The Valley Springs deposits are in several groups south, east, and north of Valley Springs, Calaveras County.

VOGELSANG RANCH.

The chrome deposits on the Vogelsang ranch are about a mile south of Calaveras River and about 5 miles southeast of Valley Springs. They consist of a series of lenses of varying size in serpentine arranged along a line trending approximately N. 45° W. Chromite can be traced for 600 or 700 feet along the strike; in this distance five or six lenses outcrop. All have their larger diameter parallel to

[a] Turner, H. W., Jackson folio (No. 11), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

the strike and are separated from one another by barren stretches of several hundred feet. The largest lens has a maximum width of 10 to 15 feet and is 40 or 50 feet long; the second largest is 3 feet wide and 30 feet long. The width of the largest lens is shown by surface ore outcrops, but partings of serpentine may occur in it. The other deposits range down to a foot or less in width and to 5 or 10 feet in length. (See fig. 14.)

The lenses are nearly vertical or dip steeply to the northeast, this being the same dip as that of the schistosity of the associated rocks. They occur in the serpentine 25 to 50 feet from its contact with amphibolite schist, the string of deposits running along northeast of this contact and nearly parallel with it. The amphibolite schist has a well-developed schistosity, and thin slabs of it have resisted erosion and rise from a foot to 3 feet above the soil all along the contact, looking like gravestones. In strike and dip this schistosity is approximately parallel to the contact and to the chromite zone.

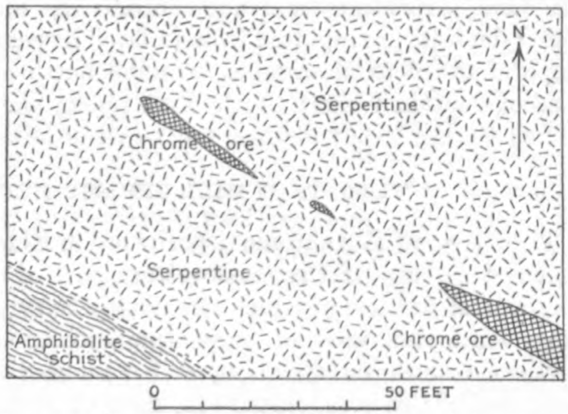

FIGURE 14.—Horizontal plan showing part of the chromite-bearing zone at the Vogelsang deposits, 5 miles southeast of Valley Springs, Cal.

The ore is very pure, glossy black, and coarsely crystalline. It is hard, heavy, and massive and can be removed in large fragments. Smooth fracture planes occur in it here and there and along some of these there are thin stringers of serpentine. In the mass of the ore, however, serpentine is almost or entirely absent, the ore thus being of high grade. The lenses are very irregular in their occurrence. One lens was found to pinch out altogether at one end about 4 or 5 feet from a point where it was 3 feet wide, while the other end continued for about 20 or 25 feet, decreasing gradually in width.

The contact of the chrome and serpentine is sharp, little or no chrome occurring in the wall rock and little or no serpentine in the ore. The serpentine is slickensided and schistose and of greenish-blue or gray color, the hanging-wall rock being apparently more decomposed than the foot wall.

A little ore has been removed for use as a furnace lining in the copper smelter at Campo Seco, but the deposits remain practically untouched. Their depth can therefore not even be estimated, but probably 500 to 1,000 tons of ore is in sight.

PINE TREE CHROME MINE.

The Pine Tree cnrome mine is about 1½ miles north of the Vogelsang deposits and about half a mile north of Calaveras River, in the same serpentine area that contains the deposits just described. It consists of a narrow open cut 30 or 40 feet long, in serpentine. Several hundred feet northeast of the cut are outcrops of massive and schistose amphibolite with areas of dark-red stained jasper. No ore is visible in the cut, all having been removed and used for lining furnaces at the Campo Seco copper smelter, but fragments on the dump show it to have been an intimate mixture of chromite and dark-green massive serpentine.

OTHER DEPOSITS.

Several small occurrences of chrome are found about 5 miles north of Valley Springs, south of Mokelumne River, in a continuation of the same serpentine area that contains the mines described above. Other deposits are reported from isolated serpentine areas on the west slope of the Bear Mountains, 10 miles northeast of Milton [a] on the land of Captain Wright, on the Pool ranch, and on the Tower ranch, in Salt Spring Valley about 9 miles east of Milton.

FLAGSTAFF HILL CHROME DEPOSITS.

The Flagstaff Hill chrome deposits are in Eldorado County, 8 miles south of Auburn, in the northwestern part of the serpentine belt in the central portion of which the Valley Springs deposits occur. A large lenticular area of serpentine crosses Flagstaff Hill [b] in a northwest-southeast direction, and a number of smaller lenses lie northeast of this area, on the east slope of the hills north of Flagstaff Hill. The inclosing rock is amphibolite and amphibolite schist.

The principal deposits of chrome are in one of the small serpentine lenses about 2 miles north of Flagstaff Hill and about halfway up the east slope of the ridge. Several trenches have been dug, but the ore remains on the dumps and apparently none has been shipped.

The ore is in every way similar to that of the San Luis Obispo district, occurring in serpentine as granules and small particles varying in size and closeness of spacing. Most of the ore is fine grained and varies from high grade to low grade, according to the amount of serpentine present. It occurs in small indefinite pockets which trend approximately north and south and grade into the surrounding serpentine.

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[a] Turner, H. W., Jackson folio (No. 11), Geol. Atla- U. S., U. S. Geol. Survey, 1894; Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 267.

[b] Lindgren, Waldemar, Sacramento folio (No. 5), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

THE ORIGIN OF CHROME ORE DEPOSITS.

PREVIOUS INVESTIGATIONS.

The origin of primary chromite deposits—that is, those occurring as pockets and lenses in serpentine and associated basic rocks—has been discussed by various investigators.[a] Some of these, such as Von Groddeck and Power, have advanced hypotheses that chrome ore deposits have a fairly recent origin, being formed during the natural process of oxidation which accompanies the hydration and weathering, resulting in serpentinization. Meunier, on the other hand, as a result of chemical study, believed that they may have originated by pneumatolytic processes shortly after the intrusion of the magma. Most commonly, however, chromite deposits have been described as products of magmatic differentiation formed by the segregation of chromite particles during the intrusion and cooling of the magma. This view is held by Vogt, Pratt, Hall and Humphrey, Cirkel, and many others.

Chromic iron ore deposits may be likened in many ways to titaniferous iron ore deposits, the former occurring in peridotite (dunite, saxonite, wehrlite, etc.), and its alteration product, serpentine, while the latter occur similarly in gabbro, anorthosite, and associated rocks. The peridotites carry chromic oxide in varying though nearly always recognizable amounts,[b] but titanic oxide is present only sparingly. On the other hand, gabbros carry definite amounts of titanic oxide, but the chromic oxide present in them is negligible. Pyroxenites, the intermediate rocks between the gabbros and the peridotites, carry small quantities of both chromic oxide and titanic oxide, the former, however, being generally in excess. This suggests that chromite is present as an original constituent in peridotites as ilmenite is present in gabbros, magnetite occurring in both.

Von Groddeck advocated the hypothesis that chromite deposits, because of their intimate association with serpentine, were formed during the serpentinization of the original rocks such as peridotites and dunites. He believed that during the process of hydration of the magnesian silicates the iron present, which generally separates out

[a] Pratt, J. H., and Lewis, J. V., Corundum and peridotites: North Carolina Geol. Survey, vol. 1, 1905, Chromite, pp. 369–390.

Pratt, J. H., Chromite or chromic iron ore: Mineral Resources U. S. for 1900, U. S. Geol. Survey, 1901, pp. 897–898.

Hall, A. L., and Humphrey, W. A., On the occurrence of chromite deposits along the southern and eastern margins of the Bushveld plutonic complex: Trans. Geol. Soc. South Africa, vol. 11, 1908, pp. 69–77.

Power, F. D., Mineral resources of New Caledonia: Trans. Inst. Min. Met., vol. 8, 1899–1900, Chromium, pp. 439–442.

Cirkel, Fritz, Report on the chrome iron ore deposits in Eastern Townships, Province of Quebec: Dept. of Mines, Canada, Mines branch, 1909.

Vogt, J. H. L., Beiträge zur genetischen Classification der durch magmatische Differentiationsprocesse und der durch Pneumatolyse entstandenen Erzvorkommen: Zeitschr. prakt. Geologie, 1894, Chromeisenerz, pp. 384–393.

Meunier, St., Contribution à l'histoire du fer chrome: Compt. Rend., vol. 110, 1890, pp. 424–425.

Von Groddeck, Lehre von den Lagerstätten der Erze, 1879, p. 146.

[b] Vogt, J. H. L., op. cit., p. 387.

as magnetite, would, if chrome minerals such as chrome diopside, picotite, and others were present, unite with the chromic oxide in these to form chromite. Vogt and Pratt, however, have shown that chrome occurs with peridotite as well as with serpentine, thus making Von Groddeck's hypothesis untenable.

Power, in his study of the New Caledonia chrome deposits, finds that besides being disseminated in small grains through the serpentine the chrome is concentrated along joints and water channels that could not have existed in the igneous mass at the time of solidification; he therefore concludes that even though chromite is apparently almost insoluble there must be some natural agent capable of decomposing it so that it may be redeposited. He makes the following statement:[a]

The serpentine, as previously mentioned, occurs in bands; the longer axis of the chrome ore lenses corresponds with the general strike of these bands. The chromite does not occur in one solid mass, but is found in joints in the serpentine and in the sandwiched beds. One may find grains of chromite peppered through the serpentine even outside the limits of the workable deposits; the ore itself does not shade off gradually into serpentine but shows a sharp line of demarcation. Now, if this chromite were due to differentiation in the molten magma one would expect the ore to pass gradually from rich to poor and thence insensibly into serpentine; instead of this, however, we find it occupying joints which could not have existed until the rock had solidified. That chromium, in the form of chromite or picotite, was an original constituent of the eruptive rock is shown by microscopic slides which give examples of ores of these minerals—which one it is difficult to determine—partly in olivine and partly in serpentine due to the alteration of olivine, the chromite grain itself showing no signs of alteration. That it is difficult to satisfactorily demonstrate how the chromite got transferred to joints considering its difficultly soluble nature we admit; still we find the chrome iron ore occupying natural water channels in the rock, sometimes with a thin coating of chrome ocher, showing that there is still some natural agent in force capable of decomposing the chromite.

Although hypotheses of recent deposition account for a few isolated occurrences of chrome ore which are otherwise difficult to explain, they do not fit the predominant and characteristic occurrences. For these the theory of magmatic segregation is the only tenable one, though undoubtedly in some places later decomposition and alteration has modified the nature of the deposits. The following exposition of the origin of the chrome-ore deposits in North Carolina by magmatic segregation is given by Pratt and Lewis:[a]

The large deposits of chromite in North Carolina occur in peridotite rock near the contact of this rock with the inclosing gneiss and where there is but a small amount of chromite, either in pockets or in grains or crystals. These are more abundant near the contact and diminish in number toward the center of the mass of peridotite. * * *

The constant occurrence of the chromite in rounded masses of varying proportions near the contact of the peridotite with the gneiss and its occurrence in the fresh, as well as the altered, peridotite indicate that the chromite has been held in solution in the molten mass of the peridotite when it was intruded into the country rock, and that it separated out among the first minerals as this mass began to cool.

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[a] Op. cit.

As has been said, the peridotite (dunite) magma, holding in solution the chemical elements of the different minerals, would be like a saturated liquid, and as it began to cool the minerals would separate or crystallize out, not according to their fusibility but their solubility in the molten magma. The more basic portions being, according to the general law of cooling and crystallizing magmas, the less soluble would be the first to separate out. These would be the oxides containing no silica—in the present case the chromite, spinel, and corundum. These minerals would solidify or crystallize out where the molten magma first began to cool, which would be at the contact of the mass with the country rock; convection currents would tend to bring new supplies of material to the outer boundary, which would deposit its chromic oxide as chromite.

The more fluid a molten mass of rock becomes the more favorable will be the movements and other conditions in this molten mass to the bringing about of these changes, and it is in these very basic magnesian rocks that we find the best illustration of the separation and concentration of the more basic minerals.

This would account for all the irregularities of the chromite deposits—their pockety nature, the shooting off of apophyses from the main masses of the chromite into the peridotite, the widening and pinching of the chromite "lodes," and the apparent nonrelation or nonconnection of one pocket of chromite with another. There has not been sufficient work done in the North Carolina chrome mines to demonstrate exactly the position and relation of the chromite deposits to the gneiss or other country rock, and in the description of other chrome mines but little light has been thrown on this point. The chromite would be concentrated near the borders of the peridotite in rounded masses, with offshoots penetrating into the peridotite. The line of contact near the gneiss would be sharp and nearly regular, while with the peridotite the contact would be very irregular. The pockets of chromite found in the midst of a peridotite formation, which at the present time are isolated and have no connection with each other, were at the time of their formation part of the chromite concentrated near the border of the peridotite, but the rapid erosion to which these rocks have been subjected has worn them down to their present condition. Again, there would be a somewhat gradual passage from the chromite to the pure peridotite.

Hall and Humphrey, in connection with their work on the chromite deposits in the Transvaal, examined the ores microscopically and found that the chromite grains show perfect crystal outlines, their edges in many places encroaching on other crystals. They say:[a]

In all the thin sections examined the chromite is found in small, well-defined grains, possessing very good crystal outlines, and this evidently points to the conclusion that the ore particles were among the first constituents to crystallize out. The same also holds good in those cases where the grains apparently envelop large crystals of enstatite or hypersthene and wrapped round them to produce a kind of network resembling the well-known mesh structure seen in highly serpentinized olivine rocks; for although such an appearance seems to indicate that the central rhombic pyroxene belongs to a phase of crystallization preceding that of the granular chromite, one frequently finds along the edge of the former some of the grains of the ore partially surrounded by enstatite and lying in a little indentation running into the latter. Since these two minerals constitute practically the entire rock, the residual mother liquor left after the separation of the chromite must have had a composition agreeing closely with that of the particular rhombic pyroxene met with, so that finally the magma would consolidate as a whole, thus producing the rude kind of cellular structure alluded to.

The gradual though rapid transition from the purer ore, within the veins, to an enstatite rock, or hypersthenite, still containing a fair amount of chromite, but with a much larger proportion of feldspathic material, as well as the absence of a sharp line

[a] Op. cit.

of division between ore and country rock, clearly points to the conclusion that these deposits are of igneous origin and must be regarded as due to local concentration of scattered chromite grains as one of the factors in the differentiation of the magma of the Bushveld plutonic complex.

The mode of origin of these chromite deposits is, therefore, similar to that of numerous occurrences associated with basic igneous rocks in other countries.

Cirkel, in a recent study of the Canadian chrome deposits, indorses the magmatic segregation theory with the following statement: [a]

As to the Canadian chromite deposits, it is quite evident that according to microscopical investigations the present serpentine is a derivative from olivine or peridotite, the dehydrated magnesian rock. The formation of chromite is explained by the oxidation of chromium (which is supposed to have been originally present in the rock) to chromic oxide, and the association of the latter with iron protoxide, which has also been formed through the oxidation of the iron which formed an accessory mineral of the rock. Of course the actual formation of chromite must have been effected during the cooling or solidification of the magma under conditions which can not be sufficiently explained; pressure and different temperatures very likely have facilitated these transformations; at any rate it is quite certain that according to the law of solubility chromite must have crystallized first out of the magma, and this crystallization or accumulation was apparently greatest where the cooling was quickest—that is, at the contact of the serpentine with some other rock. This does not mean, however, that chromite is mostly found close to the contact of serpentine with the country rock through which the original peridotite penetrated, for we find to-day excellent chromite deposits away from such contacts. It is evident also that the manner in which the crystallization or accumulation in different parts of the serpentine took place is responsible for the great irregularity of the deposits, the pockety nature and the lack of connection between the deposits, and also for the disseminated form in which the ore occurs. These irregularities were further accentuated through the shifting and displacement through which the rock had to pass after the deposition of the mineral, for we observe that the ore bodies sometimes are abruptly cut off and displaced through slickensides.

Vogt,[b] after a careful and comprehensive study of the chrome deposits of northern and central Norway, comes to the following conclusion with regard to their origin:

Because of the regular association of chromite deposits with the peridotite; because of the gradual petrographic change from the normal peridotite to chromite peridotite with constantly increasing chromite; because of the absence of pneumatolytic minerals; and lastly, because of the fact that the chromite of the chromite peridotite was formed before the cooling of the surrounding MgO-FeO-silicate magma, we draw with certainty the conclusion that the chromite deposits are basic segregations in the peridotite.

At times these chromite concentrations have cooled in situ, while at other times they have broken through surrounding rock in veins or "schlieren."

THE CALIFORNIA DEPOSITS.

The California chromite deposits examined by the writer may be grouped under three heads—(1) deposits of hard black ore mixed with serpentine and grading into the surrounding serpentine, (2) deposits of hard black ore containing little or no serpentine and hav-

[a] Op. cit.

[b] Op. cit., p. 393.

ing a sharp contact with the surrounding normal serpentine, and (3) deposits of more or less disintegrated soft gray ore in decomposed serpentine.

To the first class belong all the deposits near San Luis Obispo, those at Flagstaff Hill, and some of those near Valley Springs. They may be described as concentrations of chromite particles formed while the magma was fluid, and cooled and consolidated without accompanying deformation. These are typical magmatic segregations, the origin of which is well described by Pratt in the extract given above. Pratt, however, attempts to explain only those deposits which occur near the contact of the intruded rock. In California numerous large deposits occur within the serpentine masses at considerable distances from the borders, and therefore further explanation is necessary.

Various processes of physical chemistry are active in the differentiation of magmas, and three of these are important in the concentration of chromite deposits—(1) fractional and selective crystallization, causing a separation of the most basic constituents from the rest of the magma; (2) pressure due to gravity, causing a concentration of heavy minerals in the lower portion of the magma reservoir; (3) convection currents which carry new material to the cooler portions, especially along the contacts, and tend to coat them with early crystallizations. All these processes are active in the formation of the deposits along the contact with older rocks, but only the first two play an important part in the formation of deposits away from the borders.

When a magma begins to cool the basic constituents tend to crystallize out first, because they are the least soluble. In a peridotite magma these would be largely chromite with some spinel and perhaps magnetite. They would separate out first where cooling began first, principally near the periphery of the reservoir or around included rock masses. As a result of unequal cooling in different parts of the magma convection currents would be set up, bringing hot lavas to the cooler portions of the mass. The chromite in these convection currents would join the chromite already crystallized in the cooler zone and thus the deposits would begin to grow. A layer of molten rock for a varying distance from the contact with the intruded rock would probably become so viscous immediately after the intrusion of the magma that but little concentration could occur in it; thus the barren zone between the contact and the ore lenses would be accounted for.

While this concentration along the contacts was taking place there would doubtless be a settling of heavier particles in other parts of the reservoir, due to gravity, soon causing a concentration in the lower portion. Both Vogt and Kemp[a] have considered this process as the principal one in the formation of titaniferous iron-ore deposits. If the magma were perfectly homogeneous and had the same temperature and gaseous content throughout, this concentration would doubtless be regular over the entire lower portion of the reservoir. However, any slight variation in the above-named properties or in basicity would cause a localization of concentration and such local points once established would act as centers of concentration, thus resulting in the segregation of basic minerals, in this case largely chromite, into deposits. Convection currents and other movements in the magma would at first interfere with the settling due to gravity, but after centers of concentration were once established such movements would aid in their growth. The result of these processes operating in a peridotite magma would be a local development of chromite deposits along contacts and in the lower part of the reservoir. Later movements of the magma, however, would doubtless alter the position and location of many of the centers of concentration, so that deposits might occur anywhere in a peridotite mass. Further eruption might even take place after such differentiation.

Chromite occurrences of the second type were seen at only one locality—that of the Vogelsang deposits near Valley Springs. They are duplicates of the Norwegian deposits described by Vogt[b] as "schlieren" and veins resulting from later movements in the magma. After the concentration of large deposits of chromite, before or after partial consolidation of the main mass of rock, the magma may be subjected to external pressures resulting in the squeezing of some parts of it into other parts and in a general deformation of the entire mass. During this process pure chromite masses or, as described by Vogt, mixtures of chromite with enstatite or olivine may be squeezed between masses of normal peridotite that may be fluid or partly consolidated. Thus perfectly sharp contacts would be established. Elsewhere the masses of chromite may be simply deformed by shearing and squeezing without much change of position. These processes would produce many of the chromite veins which have been by some investigators attributed to later deposition by orebearing waters.

Doubtless further deformation of the ore bodies takes place during the serpentinization of the inclosing peridotite. This change, due to the hydration of the magnesian silicates, is accompanied by a great increase in volume (33 per cent, according to T. Sterry Hunt, if there is no loss of silica), causing the development of immense

[a] Vogt, J. H. L., Om dannelse af jernmalmforekomster, Kristiania, 1892. Kemp, J. F., Titaniferous iron ores of the Adirondacks; Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 417-419.

[b] Vogt, J. H. L., Beiträge zur genetischen Classification der durch magmatische Differentiationsprocess und der durch Pneumatolyse entstandenen Erzvorkommen: Zeitschr. prakt. Geologie, 1894, Chromeisenerz, pp. 384-393.

pressures which result in widespread shearing, faulting, and slickensiding. During the alteration of olivine and pyroxene to serpentine the iron present in these minerals separates out as magnetite and becomes disseminated through the serpentine. Adjacent to chromite deposits the magnetite may join the chromite and cause a dilution of the latter locally.[a]

Deposits of the third type are formed by weathering from either of the above-described types and are illustrated by the Mendenhall occurrences near Livermore. Here disintegration of the chrome-ore deposits has taken place near the surface with partial decomposition, resulting in the so-called "gray chrome ore." The wall-rock serpentine is decomposed and disintegrated to a much greater extent than the ore, and the ore deposits have probably been deformed considerably because of slumping. Numerous small bright-green specks of chrome ocher occur in the ore masses, bearing witness of at least a partial solution and subsequent hydration of the chromite.

[a] Lindgren, Waldemar, personal communication.

AN OCCURRENCE OF MONAZITE IN NORTHERN IDAHO.

By F. C. Schrader.

LOCATION AND TOPOGRAPHY.

The occurrence of monazite here described is located in the southeastern part of Nez Perce County, Idaho, about 120 miles southeast of Spokane and 60 miles east of Lewiston. The nearest railroad station is Greer, 28 miles to the west, on the Clearwater branch of the Northern Pacific Railway. The locality is some 1,500 feet higher than Greer and is reached by a wagon road, following the famous Lolo trail that crosses the Bitterroot Range. The deposits are about 10 miles east of the village of Weippe and the same distance south of the mining camp of Pierce, in the western border of the Clearwater National Forest. The northern part of the field may also be reached by a wagon road joining the main road at Brown Creek, about 5 miles beyond Weippe.

The deposits examined are on Musselshell Creek, a tributary of Lolo Creek. The latter flows into Clearwater River, which joins Snake River at Lewiston. Musselshell Creek drains a part of the western border of the Clearwater Mountains at an elevation of 3,000 to 4,000 feet above sea. These mountains are shown by Lindgren[a] to be carved from an old uplifted westward-sloping plateau, now deeply dissected into a rough topography characteristic of eroded granitic rocks. The canyons, valleys, and gulches are deep and the ridges high and sharp. The region is heavily timbered and has a considerable annual precipitation. In the western portion, however, near the region where the mountains give way to the younger Columbia River basalt plateau (fig. 15), the topography becomes less rugged. Here the upper part of Musselshell Creek occupies a narrow valley about one-fourth of a mile in width from ridge to ridge and sunk to a depth of several hundred feet below the summits of the adjacent hills, which represent roughly the general level of the plateau or upland.

[a] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904.

GEOLOGY.

The country rock in this portion of the mountains, as shown in figure 15, has been sketched by Lindgren as pre-Tertiary granite and its closely allied rocks, quartz monzonite and diorite, of massive structure, in which are embedded bands or local bodies of old metamorphic gneiss and schist. The granite itself, a normal light-gray medium-grained rock, of great constancy in petrographic character, is found on analysis to stand very close to quartz monzonite.[a]

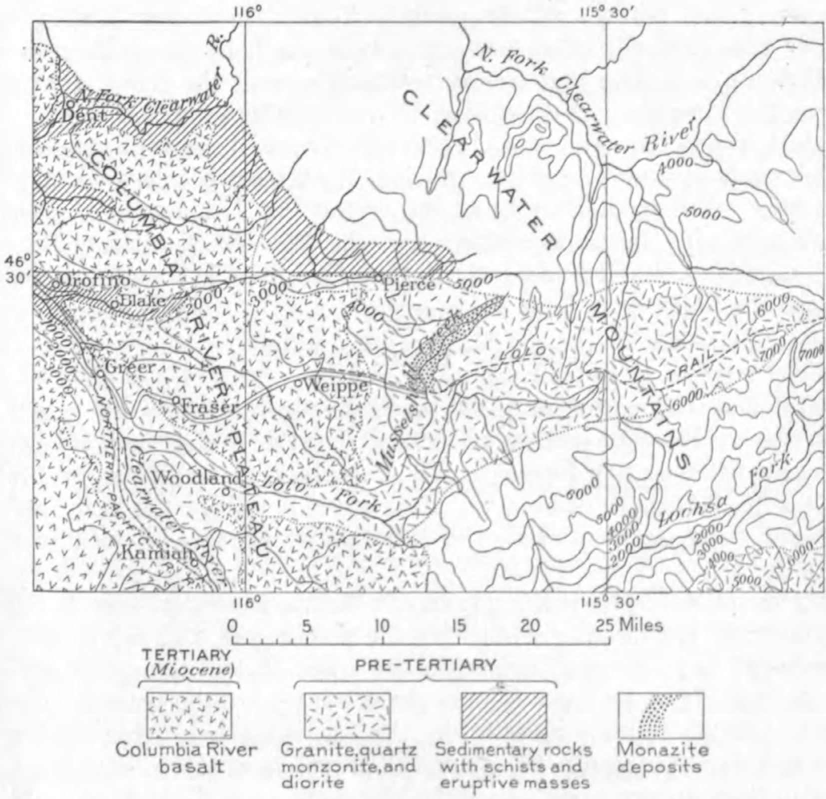

FIGURE 15.—Sketch map showing location of monazite deposits on Musselshell Creek, Nez Perce County, Idaho. (Adapted from Pl. I, Prof. Paper U. S. Geol. Survey No. 27.)

In favorable places on the ridges and side slopes of the valleys disintegration of these rocks has covered the surface with granitic residual soil or loam several feet thick. The bottom of the valley, 250 feet wide, is covered by a sheet of recent alluvium about 8 feet in average thickness. The upper 3 or 4 feet of this alluvium underlying the creek bottom or valley flat is usually composed of humus, soil, loam, muck, sand, and clay in various amounts; the lower 4

[a] Prof. Paper U. S. Geol. Survey No. 27, 1904, pp. 17-20.

feet consists essentially of recent stream gravels and sand, resting upon the granite bed-rock floor.

The gravels are mainly granitic and, together with their sand and mineral content, are derived from the parent rocks in the immediate vicinity. They range from fine to coarse. Although stream-laid and to a moderate degree waterworn, on the whole they are more subangular than rounded.

Associated with these recent gravels, particularly on the rim rock and extending thence to higher ground, are also local deposits of ancient river gravel or "old wash." This ancient gravel is composed almost wholly of waterworn or well-rounded pebbles of quartz and dense quartzite and contrasts strongly with the recent gravel deposits. It is known to exceed 11 feet in maximum thickness.

Both the recent and the old gravels contain low-grade deposits of placer gold, which have been worked at different points with varying success from time to time during the last half century. The most extensive workings are those of the Musselshell Mining Company, at Musselshell Falls, near the middle of the field, a few miles above the Lolo trail.

MONAZITE DEPOSITS.

The monazite occurs as placer sand chiefly in the gravels above described. It was recently recognized by the Musselshell Mining company in operating for gold. The deposits were examined by the writer for a distance of about 7 miles, extending from the Lolo trail crossing northeastward along the creek nearly to its head, as shown in figure 15.

Owing to its high specific gravity, which is generally over 5, the monazite in the recent gravels, like the placer gold with which it is associated, is more concentrated in the lower part of the gravel and on the underlying bed rock than in the upper part of the gravel. The sand seems to be more plentiful in the ancient gravels than in the recent. For this reason these ancient gravels seem to be worthy of exploitation to bed rock, for their monazite as well as their gold content.

Likewise owing to its high specific gravity the monazite tends to remain with and is difficult to separate from the gold and heavier black-sand minerals, such as ilmenite, magnetite, garnet, and zircon. It is, however, more widely distributed than the gravel and the gold, for it is found also, though in less concentrated form, in the talus, disintegrated granite, and residual soil in the gulches and on slopes rising several hundred feet above the creek. What is commonly reported to be the best monazite prospect in the field is about a mile east of the falls of Musselshell Creek, on fairly high ground, in the southern part of the property known as the Little John claim. This deposit is apparently on one of the upper gulches of Gold Run Creek, a tributary to the Musselshell in the southern part of the field. Search in this locality failed to reveal any opening, but it was probably concealed by a considerable depth of snow that lay on the ground at the time.

It is probable that the monazite extends not only throughout the length of Musselshell Creek valley, but that it may have a much wider extent and may occur also in adjoining valleys. This inference is supported by a letter received from Mr. I. D. Cleek, superintendent of the Oro Grande Placer Mining Company at Pierce, and an experienced operator in the Musselshell and Pierce districts, who states that the monazite is much more plentiful at Pierce than on Musselshell Creek.

The monazite sand on Musselshell Creek is yellowish brown, with a greenish tinge in places, and has a resinous luster. It is fine grained, with the grains predominantly subangular and in large part exhibiting bright faces.

Eleven samples of the sand were collected at intervals to show its general distribution throughout the field. These were concentrated by David T. Day by means of magnetic machinery and by washing, and were found to contain from 7½ to 45 per cent of monazite, averaging about 29 per cent. Subsequently chemical analyses were made of the nonmagnetic portions of four of the samples by R. C. Wells, with results which conclusively identify the mineral monazite.

Analyses of monazite sands from Musselshell Creek, Nez Perce County, Idaho.

[Analyst, R. C. Wells.]

	No. 5. (162).	No. 14 (163).	No. 19 (164).	No. 21 (165).
P_2O_5	10.9	8.9	15.5	8.7
ThO_2	1.20	1.15	1.85	.88

The more interesting constituent revealed by the analyses is the thoria, for the commercial value of the monazite depends wholly on its available thoria content. The average in these samples was 1.3 per cent. The thoria is extracted chemically and is used in the manufacture of mantles for incandescent gas lights.

Computation from the content of phosphoric acid (P_2O_5) shows that the sands range from 31.8 to 55.36 per cent monazite, and average about 40 per cent. Estimates made by D. B. Sterrett of the percentage of monazite in the samples not analyzed agreed rather closely with the determinations based on the chemical analysis.

When cleaned to 90 per cent, the usual commercial grade, the sands contain approximately 3 per cent of thoria, which is about the average of a large number of samples from northern Idaho reported to have been analyzed by the Welsbach Light Company. On a basis of pure monazite the sands would contain 3.3 per cent of thoria.

As some of the phosphoric acid on which computation of the monazite is based may be derived from impurities present in the sands, the above-stated percentage of monazite in the samples analyzed is probably too high and that of thoria correspondingly too low. No allowance being made for this fact nor for the monazite lost during concentration both in the field and in the laboratory before the sand reached the chemist, and the sand of 90 per cent grade being rated at a value of 5 cents per pound, tests on the gravels show that they carry values in monazite ranging from 1 to 7 cents a cubic yard, or an average of about 3 cents. It is difficult to place a correct value on cleaned monazite carrying so low a percentage of thoria, as the companies manufacturing thoria compounds generally obtain sands carrying 5 per cent or more of this oxide. The present market price for monazite is 12 cents a pound for sand carrying 90 per cent of monazite and 5 per cent or more of thoria. The value of monazite with a smaller percentage of thoria is not proportionately less, as the cost of extraction of this oxide is considerably greater when the thoria content is low than when it is high.

Although at this figure the deposits are not workable for the monazite value alone, it is possible that the monazite can be saved with profit as a by-product in connection with gold-placer operations, and such saving may enable some ground to be handled with a margin which could not be worked for its gold content alone. As the value of the mineral, the extent of its occurrence, and the facilities that exist for saving it are not generally known, no effort has yet been made to save the monazite in mining operations in this part of the State.

Monazite is usually mined by concentration in sluice boxes, much the same as placer gold. Owing to its high specific gravity it is easily saved by ordinary methods of washing on the Wilfley or any similarly constructed table. As magnetic iron, titanic iron, garnet, and similar minerals associated with monazite respond to magnetic attraction a fairly clean separation can be effected with the Wetherill electro-magnetic separator.

ORIGIN AND GENERAL DISTRIBUTION OF MONAZITE IN IDAHO.

The following note on the known and inferred distribution of monazite in Idaho may prove of value to operators in regions where this mineral, hitherto unrecognized, may be present in commercial quantities.

Monazite was first reported in the Western States from Idaho Basin, Boise County, in southern Idaho, by Lindgren [a] in 1896. It

[a] Lindgren, Waldemar, Mining districts of Idaho Basin and Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 677-679.

is widely distributed in the gravels of this locality, and its commercial exploitation has recently been undertaken on a considerable scale by the Centerville Mining and Milling Company at Centerville, with reported promising results.

In 1905, as a result of investigations made by the Geological Survey of the useful minerals contained in the black sands of the Pacific slope, sands containing monazite were received or reported from various localities, mostly in Idaho and Oregon. The Idaho localities are as follows:[a]

Ada County:
- Boise.
- Boise Basin.
- Snake River.

Boise County:
- Centerville.
- Grimes Creek.
- Red Fox claim.
- Placerville.
- Lardo.
- Garden Valley.
- Marsh.
- Idaho City.

Canyon County:
- Payette River.

Idaho County:
- Elk City and district.
- Resort.
- Florence.
- Marshall Lake district.
- Baker Gulch, Crooked River.
- Penmans Fork, Big Creek.
- Syringa.
- Camp Howard district.

Lemhi County:
- Leesburg.
- Leesburg Basin, Arnet Creek.
- Leesburg Basin, Wards.

Lincoln County:
- Minidoka. } Snake River.
- Shoshone. } Snake River.

Nez Perce County:
- Orofino.
- Dent.
- Lewiston (Clearwater River).
- Salmon River.
- Pierce City and district.

Owyhee County:
- Oreana, Snake River.

Shoshone County:
- Rhodes Creek.
- Near Dent.

Washington County:
- Meadows.
- Central Idaho, Salmon River.
- Snake River.
- John Day Creek.

Lindgren concluded that the monazite in the Idaho Basin was derived by disintegration from the local granite, of which it forms an original constituent. Similarly, the monazite of Musselshell Creek, recently examined by the present writer, seems without doubt to be derived from the pre-Tertiary granite and associated rocks. Many of the heavy minerals found in the sands of the gravels may be observed macroscopically or with a pocket lens in these rocks.

According to Lindgren, who has investigated both fields, the granite of Idaho Basin and the granite on Musselshell Creek are very closely allied if not the same rock. Both areas seem to be part of the same great granitic batholith that extends north and south through all of central Idaho, with a length of 300 miles, and eastward through the

[a] Day, D. T., and Richards, R. H., Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, pp. 1194-1201.

Bitterroot Range into Montana, with a width of 50 to 100 miles, "constituting one of the largest granitic batholiths of the continent."[a]

The manner of occurrence and the distribution of the monazite deposits on Musselshell Creek and in Idaho Basin and the distribution of the reported localities, all within or near the granite batholith area, are suggestive of a genetic relation between the monazite and the granite. Accordingly, it seems possible that the general distribution of monazite in Idaho may be roughly coextensive with the batholith area and the eruption of these granites into the included and inclosing older rocks. The monazite deposits without the area of the batholith may also have their origin in the smaller eruptive masses, probably offshoots from the same batholith, intruded in the outlying schists and sedimentary rocks. Deposits occurring under such conditions resemble those of the Carolinas in the southern Appalachians. The occurrence of monazite around Dent, on the North Fork of Clearwater River, in the northwestern part of Idaho (see fig. 15), furnishes a good example of this type.

If the above inferences are correct, it would seem that a knowledge of the distribution of granitic rocks of this class, whether occurring as batholitic masses or local intrusive bodies, may be utilized in searching for monazite deposits. If, as reported by the Centerville Mine and Milling Company, monazite sand of 90 per cent grade from Idaho Basin contains 4½ to 5 per cent of thoria,[b] it seems reasonable to infer that sand containing similar thoria values may yet be found elsewhere in the Idaho field.

PARTIAL BIBLIOGRAPHY ON MONAZITE.

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[a] Lindgren, Waldemar, Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 17.

[b] Sterrett, D. B., The production of monazite and zircon in 1908: Mineral Resources U. S. for 1908, pt. 2, U. S. Geol. Survey, 1909, p. 792.

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PLATINUM IN SOUTHEASTERN NEVADA.

By Howland Bancroft.

INTRODUCTION.

Early in the month of June, 1909, the writer, at the request of David T. Day, made an investigation of the Key West and Great Eastern prospects in Clark County, Nev., a short sketch of which has already been published.[a] Since that time a more detailed study of the specimens has been made and assays for gold, silver, platinum, and nickel have been furnished by competent analysts. Because of the necessary brevity of the former sketch and of the interest connected with the results of the assays made since its publication, it has been thought advisable to prepare a more detailed account of the results of the investigation.

Sincere thanks are due to the officers of the Key West Company for much information pertaining to the properties examined. To Mr. Waldemar Lindgren the writer is especially indebted for valuable assistance in the preparation of this paper.

LOCATION.

The prospects examined are located in the Copper King mining district, Clark County, Nev., about 16 miles a little west of due south of Bunkerville, a small Mormon settlement on Virgin River. (See fig. 16.) The most direct route to the prospects, however, is not by way of Bunkerville, for a wagon road crosses the river several miles southwest of that place and goes practically direct to the deposits. In an air line it is just 24 miles S. 75½° E. from the Moapa station on the San Pedro, Los Angeles and Salt Lake Railroad to the district. The distance by the most direct wagon road at present is probably between 35 and 40 miles, but could no doubt be shortened 4 or 5 miles by picking out another route. The prospects are situated about 8 miles west of the Nevada-Arizona boundary line.

[a] Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 783.

GENERAL DESCRIPTION.

Reference to the St. Thomas topographic sheet of the United States Geological Survey will show the type of the country traversed between Moapa and the district examined. Moapa is located where the old California trail crosses Muddy Creek, at an elevation of 1,663 feet.

The country between Moapa and Virgin River is a desert plateau about 2,500 feet in elevation. There is hardly any vegetation, a

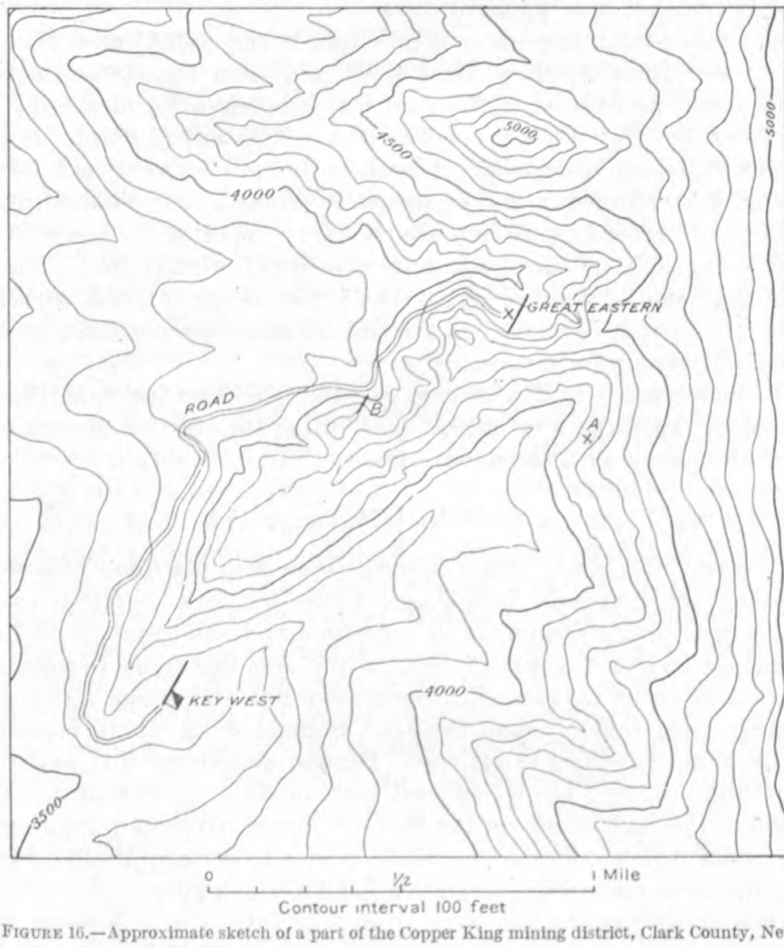

FIGURE 16.—Approximate sketch of a part of the Copper King mining district, Clark County, Nev.

total lack of water, and no habitation between the two places. Certain parts of the valley of Virgin River present a very acceptable and pleasing sight after the long ride across the desert. The river at the crossing has an elevation of 1,100 feet. The prospects are situated in the rough foothills of the Virgin Range about 8 or 9 miles from the river crossing and 2,500 feet above it. The range itself is precipitous, its highest point, Virgin Peak, attaining an elevation of 7,500 feet. Apparently it is formed mainly of thick sedimentary limestone strata.

Because of their altitude the temperature at the deposits is considerably lower than at Moapa. Early in June, 1909, it was fairly comfortable at the Key West when the heat was almost unbearable at Moapa, the thermometer there registering over 116°. During the spring, fall, and winter months the climate is said to be nearly perfect, little or no snow falls in the valleys, and there are frequently long periods of clear, pleasant days.

The nearest running water is in Virgin River, 8 or 9 miles distant. The water from the Key West shaft and from the Great Eastern adits has been utilized in the past for domestic use and also in the boiler on the Key West property with no apparent ill effects, as the writer has been informed. Whether the prospects would afford enough water to run a mill or reduction works of any kind is rather doubtful. According to reports on the property the Key West makes 8 gallons of water a minute at a depth of 300 feet. This is 11,520 gallons of water a day. The writer is not familiar with the amount of water developed in the Great Eastern properties, but it is certainly enough for domestic use.

Timber is scarce in this vicinity and the freight on fuel from Moapa would be very expensive, almost prohibiting the erection of a smelter at the property with the present transportation facilities.

GEOLOGY.

Between Moapa and Virgin River little rock in place can be seen in crossing the plateau. This desert table-land is covered in many places with small fragments of limestone and sandstone, with here and there an outcrop of the former. In places this seems to resemble a cracked asphalt pavement, being very flat and smooth and presenting a network of small fissures. Some 4 miles out of Moapa is an outcrop of reddish sandstone. Beyond and above this, as far as the Virgin Valley, all of the rock seen in place is limestone. The rocks of the high bluffs on the west of Virgin River and apparently the rocks which underlie the whole plateau between Muddy Creek and the river are reddish sandstones of Paleozoic age.

On approaching the Key West from the Virgin, the underlying rock is seen to be a pinkish coarse-grained gneiss of granitic composition, having orthoclase feldspar and quartz in about equal amounts, with a little hornblende. Overlying this is a limestone conglomerate a few feet thick composed of rather small fragments. Above this is a pinkish limestone of considerable thickness which assumes a yellow color on weathering. This formation extends to a point within 2 miles of the Key West, where it has been entirely eroded and the underlying gneiss comes into view. About 2 miles east of the Key West the limestone reappears and is apparently of great thickness, forming very steep cliffs on Virgin Mountain. Thus a narrow strip approximately 4 miles in width of probably pre-Cambrian rocks has been exposed by the erosion of the overlying Paleozoic sediments.

The rocks in the immediate vicinity of the Key West and Great Eastern properties consist of coarse-grained gneisses apparently of granitic origin, showing distinct gneissic structure. The country rock of the deposits shows on microscopic examination of thin sections about an equal amount of quartz and feldspar, with some hornblende and a very small amount of biotite, occupying close parallel zones which emphasize the general gneissic structure. Much of the feldspar is altered to white mica (sericite or paragonite) and here and there epidote and calcite are present in small amounts. These gneisses are probably of pre-Cambrian age. The prevalent direction of schistosity seems to be northeast, with a very steep dip to the northwest. These rocks, standing almost vertically and with the accompanying jointing parallel to the shearing planes, form in places prominent ridges. Along these ridges can be seen distinctly the successive intrusions of various basic rocks, with aplite and pegmatite, all of which are common to the vicinity. The two latter rocks are evidently later than the metamorphism of the region. The most schistose of the basic intrusive rocks is almost black, the feldspar it contains making all the more prominent the perfect lamination displayed. The phenocrysts of feldspar and hornblende are small, and although the general appearance of the rock is somewhat similar to that of the ore-bearing dikes, it can readily be distinguished from them in its comparatively large content of feldspar. This hornblende schist seems to be part of the earlier series and bears evidence of considerable metamorphism. A thin section of this rock shows hornblende, plagioclase feldspar, and some quartz. The feldspars are altered in part to white mica, and the titaniferous magnetite, which has filled some of the interstices between the hornblende, has altered to leucoxene. A little pyrite is present in the magnetite; both these minerals are secondary, the magnetite filling interstitial spaces rather than crystallizing, as it would if primary.

The pegmatite is very coarse grained, having orthoclase and quartz crystals over half an inch in length and containing a large amount of mica. The aplite is of medium grain and contains much mica.

Dikes of extremely basic composition are the most interesting feature of the geology of the area and these will be described in some detail, as they represent the ore-bearing formation. As may be seen by referring to figure 16, these dikes are intruded into the gneisses in a number of places with no apparent regularity except that of direction of strike. The trend of the intrusive rocks is approximately northeast and southwest, which follows the strike of the gneiss, the dikes in general seeming to conform to the structure of the older rocks.

The extent of outcrop of the basic dikes on the surface is generally 100 feet or more, and they vary in width from 10 to 50 feet. They are rather commonly faulted both horizontally and vertically, as indicated by the fault in the Key West property and by the displacements seen in the country rock in the vicinity.

The Key West and Great Eastern prospects are the two most prominent workings in the vicinity. The former is located on the southwest end of Virgin Mountain at an elevation of 3,660 feet and the latter about a mile northeast of this place at an elevation of 4,175 feet.

PETROGRAPHY OF THE DIKES.

The ore bodies in both the Key West and the Great Eastern are simply very basic intrusions having the composition of peridotite. The Great Eastern dike, from which it was possible to obtain fairly fresh specimens, is medium grained and dark colored, almost black, showing megascopically the presence of brownish mica and pyrrhotite. A thin section shows on microscopic examination that the rock is holocrystalline; the chief minerals are augite, olivine, biotite, and enstatite, their relative abundance being in the order named. This would constitute an enstatite-mica picrite, a variety of peridotite. The rock also contains magnetite, pyrrhotite, and chalcopyrite, which are apparently of primary origin and are intimately intergrown. These minerals constitute a small relative proportion of the whole dike, but are nevertheless rather conspicuous. Chromite was also recognized. The olivine has been in part decomposed, quartz, iron-stained serpentine, and magnetite resulting. This magnetite has no apparent relation to that associated with the pyrrhotite and chalcopyrite, however, but is scattered through the interstices of the altered olivine. A specimen of the rock from this dike analyzed for the United States Geological Survey showed the presence of a trace of platinum and 0.26 per cent of nickel, but no gold or silver.[a]

Other assays made by R. H. Officer & Co., of Salt Lake City, the results of which were given by Mr. Darling, superintendent of the Key West property, show 1.5 per cent of copper, 0.9+ per cent of nickel, and 0.25 ounce of platinum for the Great Eastern dike. A recent assay made by Ledoux & Co., of New York City, of a dike cut in the lower Great Eastern adit, the results of which were kindly furnished by the Key West managers, shows the following analysis:

[a] Nickel determination by chemical laboratory, United States Geological Survey; platinum, gold, and silver by Ledoux & Co.; no assay for copper made.

Analysis of dike in lower Great Eastern adit.

Silica	24.88	Copper by electrolytic assay	2.01
Iron	19.35	Nickel	5.38
Alumina	4.21	Cobalt	.04
Lime	4.51	Platinum metals, 0.17 ounce.	
Magnesia	13.94	Gold, trace.	
Sulphur	18.02	Silver, trace.	

From a small open cut (location B on fig. 16) a specimen of another basic dike was taken. On microscopic examination this proved to be a typical hornblendite, the hornblende minerals being about 3 millimeters long and forming a holocrystalline rock. An assay showed a trace of platinum, but no nickel, gold, or silver. The presence of platinum in such a fresh rock, showing no signs whatever of metallic contents even in a thin section under the microscope, is worthy of remark. As little or no work has been done on this open cut it is impossible to give any details of the extent of the dike.

Another open cut (location A on fig. 16) is upon a dike composed almost entirely of biotite mica and pegmatite, which occupies a shear zone in the country rock. This dike probably contains no valuable metals, although no assays have been made of the material.

The Key West dike has been exposed by more workings than any other in the vicinity. However, the upper portions of the dike and the ore on the dump from the lower portions (under water at the time of the writer's visit to the camp) are extremely decomposed and altered, so that no detailed description of the constituent minerals of the dike can be given. It is reasonable to suppose, however, that the Key West and Great Eastern dikes were once of similar mineralogical composition. In the Great Eastern workings apparently there has been much more alteration, oxides and sulphides of copper having been deposited in large quantities.

Only a small amount of pyrrhotite is present in the ore from the Key West workings. This is probably due to the fact that on hydrometamorphism, such as has taken place in this dike, pyrrhotite changes to pyrite,[a] a mineral of which there is a great abundance, of both primary and secondary origin.

Assays made of the Key West ore show that the decomposed dike near the surface contained 0.1 ounce of platinum to the ton and 1.47 per cent of nickel, no gold or silver being present. One specimen of ore which contained an apparent high percentage of sulphides assayed 0.12 ounce of platinum to the ton and 5.6 per cent of nickel, with no gold or silver, copper content not being determined. This specimen shows extreme brecciation, and is composed of quartz fragments

[a] See Lindgren, Waldemar, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 181, for description of similar alteration.

cemented by pyrite and chalcopyrite. The sample which gave the highest platinum assay of all those which the writer had tested, 0.55 ounce to the ton, came from an ore body found only between levels 2 and 3, where the Key West dike is supposed to be faulted and a new ore body comes in. These levels being under water at the time of the visit to the property, the rock could not be seen in place, and the specimen was selected from the ore dump as a "picked sample." This specimen contained, besides the platinum, 4.66 per cent of nickel, with a trace of gold, and no silver. This rock may have been a peridotite originally, but is so altered that the primary constituents are impossible to determine, sulphides now forming a large part of the rock. Calcite seems to have filled all the cavities left by the alteration of the amphiboles or pyroxenes.

DEVELOPMENTS AND PRODUCTION.

The Great Eastern has been developed by crosscuts only on two levels. In all there is some 600 feet of work on the prospect. No shipment has been made from this property.

On the Key West there is a little over 3,000 feet of development work. This includes two shafts, the main one being down 312 feet, three levels, winzes, and drifts. As the lower levels of the Key West were under water, information on the workings below the 120-foot level was given by Mr. S. W. Darling, superintendent of the Key West. From this property, which has not been operated for over six years, one carload (91,600 pounds) of ore has been shipped, the contents of which are shown by the following analyses, furnished by the Key West management:

Analyses of ore from Key West prospect.

	North American Lead Co.	Ledoux & Co.
Silica (true SiO_2)	34.87	....
Iron	10.59	....
Lime	9.41	....
Magnesia	15.33	....
Alumina	6.55	....
Copper	2.30	3.50
Nickel	1.79	1.86 (Nickel and Cobalt)
Cobalt	.08	
Sulphur	6.90	....
Gold per ton (2,000 pounds)	Trace.	Trace.
Silver per ton (2,000 pounds) ....ounce..	Trace.	.35
Platinum metals per ton (2,000 pounds) ....do....	.13	.15

NOTE.—The sample contains a small trace of lead—no zinc and no arsenic; it also contains 0.3 per cent of titanic oxide.

CONCLUSIONS.

The basic dikes described contain in appreciable quantities primary magnetite, pyrite, chalcopyrite, platinum, and pyrrhotite, the last probably being nickeliferous. In the Key West dike the pyrrhotite has been largely changed to pyrite through the action of infiltrating solutions. As stated in the writer's earlier and briefer report on this district, if these properties were near a railroad or the ore could be treated on the ground, it is quite probable that they would be able to produce bullion. Under present conditions, however, working expenses would be very high.

THE VIRGINIA RUTILE DEPOSITS.

By Thomas Leonard Watson and Stephen Taber.

INTRODUCTION.

Rutile is the only one of the comparatively large number of titanium-bearing minerals that has been utilized as a source of titanium. It occurs in rocks belonging to each of the three major divisions—igneous, sedimentary, and metamorphic. Its known distribution in commercially workable deposits is limited to three widely separated localities. These are (1) the Amherst-Nelson counties area in Virginia, (2) the Kragerö area in southern Norway, and (3) a recently discovered area about 40 miles northeast of Adelaide in South Australia. So far as the writers have information the Virginia area is the most extensive of the three.

Recent detailed field studies, including mapping, of the Virginia area by the Virginia Geological Survey [a] indicate practically an unlimited supply of rutile, which can be concentrated to yield a product of very high grade, much of it containing more than 99 per cent of TiO_2. Prior to the opening of the Virginia rutile deposits in 1900 the small domestic demand for the mineral was supplied from Chester County, Pa. Since 1902 the Virginia deposits have supplied all the rutile used in this country, and much of the product has been shipped abroad. With the development of new uses of titanium—the two most important being in the manufacture of ferrotitanium for the production of special grades of steel and in the manufacture of arc-lamp electrodes—and the consequent increasing demands for rutile the prospect for the future of rutile mining in Virginia seems decidedly encouraging.

Some of the more important facts relating to the geology and development of the ore deposits in the Virginia rutile district, obtained by the writers from a recent careful study of it, form the basis of this preliminary paper.

[a] A detailed report on this important and interesting area will be published shortly as Bulletin III-A of the State Survey.

THE VIRGINIA RUTILE AREA.

LOCATION.

The rutile area of Amherst and Nelson counties lies in the west-central part of the State, along the middle western edge of the Piedmont Plateau and near the southeastern slope of the main Blue Ridge, within the foothills. It occupies the south-central part of Nelson County and the contiguous northeastern portion of Amherst County to the south, but much the largest part of it lies in Nelson County, which includes all developments thus far made. The area lies from 5 to 7 miles northwest of the Southern Railway and is accessible from Arrington and Tye River, the two nearest stations. Its position is shown in the index map (fig. 17).

FIGURE 17.—Index map showing location of Virginia rutile area.

TOPOGRAPHY.

The area mapped includes approximately 170 square miles lying within the middle western portion of the crystalline region of Virginia. The rutile-bearing formation, however, covers less than one-fifth of the total area mapped, occupying a narrow lowland belt that has a general northeast-southwest direction approximately 16 miles in length and not exceeding 2½ miles in greatest width. Its general elevation averages about 700 feet, but the surrounding country immediately to the north, east, and west rises as peaks and ridges 1,000 to 2,000 feet and more above sea level. The drainage is in general toward the southeast into James River. Tye River and its tributaries drain the largest and most important parts of the area, and Buffalo River and its northeastern tributaries drain the extreme southwestern part. Figure 18, a reconnaissance topographic map of the area, shows the outline of the rutile-bearing formation and serves to indicate in a general way the larger topographic relations outlined above.

GENERAL GEOLOGY.

The rocks in the rutile area are igneous in origin, are intensely metamorphosed, and are readily divisible into a number of distinct types which show certain marked kinships to one another, especially in mineral composition. They form a distinct comagmatic area

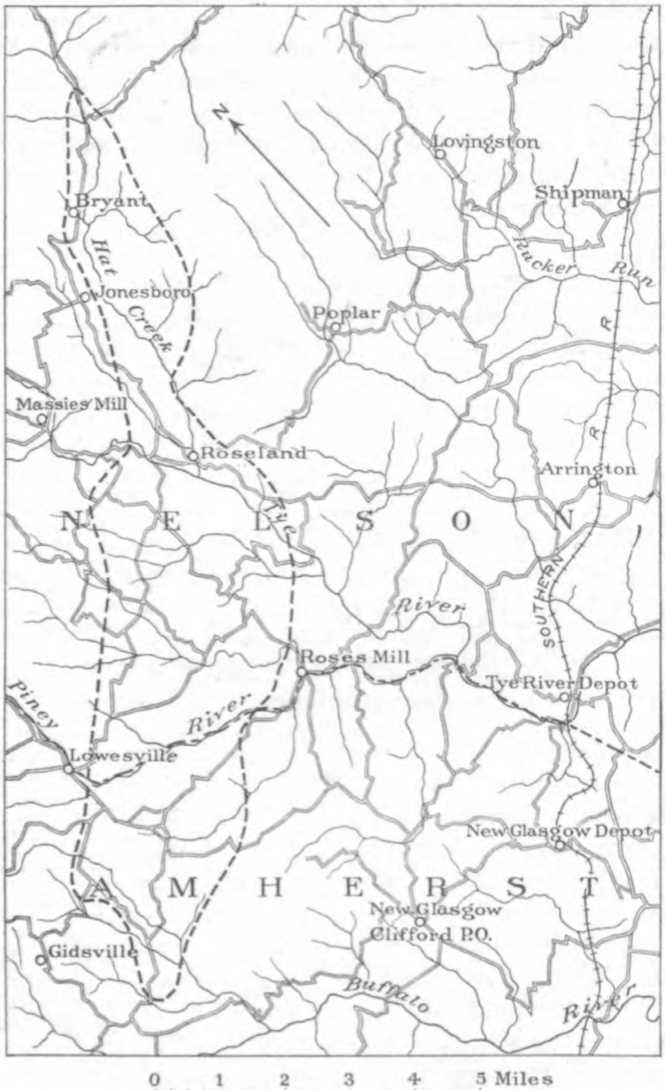

FIGURE 18.—Topographic map of Virginia rutile area. Rutile-bearing formation inclosed by heavy broken lines.

characterized by the prominence of apatite and the titanium minerals—ilmenite, rutile, and in a few places titaniferous magnetite; by a peculiar blue opalescent quartz; and by pyroxene (chiefly hypersthene) or secondary hornblende derived from the pyroxene as the dominant ferromagnesian mineral. Biotite, an important constituent in the surrounding gneisses and schists, is practically absent from the ore-bearing rocks. It occurs, however, as a minor constituent in a part of these rocks and is generally present in the nelsonite dikes, but its relations in each situation are such as to suggest probable secondary origin. In general the dominant minerals in one type make up the minor accessory minerals in the other.

The rocks are holocrystalline in texture and for the most part are even granular, ranging from very coarse grained in portions of the quartz-feldspar-hornblende formation (pegmatite) to very fine grained in some of the nelsonite and diabase dikes. They show pronounced though unequal effects of dynamic metamorphism, both in hand specimens and in thin sections under the microscope. Megascopically the most pronounced effect of metamorphism visible in most of the rocks is the development of complete or partial schistose structure. Microscopically, metamorphism is manifested chiefly in mashing—granulation, fractures, and optical disturbance of certain essential minerals—in recrystallization, and in the complete or partial change of pyroxene (hypersthene) to secondary hornblende. Other changes of a different order and kind involve the production of secondary minerals from the essential ones, chief among which may be mentioned the formation of bastite from hypersthene, leucoxene from the titanium minerals rutile and ilmenite, and sericite from feldspar. In some of the rocks biotite, chlorite, epidote, and osteolite are noted as alteration products.

PRINCIPAL ROCK GROUPS.

Named in the probable order of their differentiation, including the surrounding rocks, the principal rock types of the area mapped are (1) metamorphic igneous gneiss, including schists, (2) pegmatite, (3) gabbro, (4) nelsonite, (5) diabase. In places the rocks of types 2, 3, and 4 appear to be approximately contemporaneous.

GNEISS.

The inclosing or country rock of the area is a pronounced foliated biotite gneiss which shows in many places a considerable development of schists of various composition. Gneiss is the dominant type in this complex of metamorphic rocks and has wide general distribution beyond the limits of the rutile area throughout the Blue Ridge region of central western Virginia. It exhibits some textural and mineralogical variations, but the prevailing kind is a medium to dark gray rock, varying from a fine to medium-coarse, even-granular to porphyritic texture. The minerals recognizable with the naked eye are feldspar, quartz, and biotite.

The microscope shows the gneiss to be a metamorphosed igneous rock, derived from an original quartz monzonite, a conclusion confirmed by the analysis given below. The original porphyritic texture which characterized certain parts of the gneiss is still readily recognized, and the feldspar phenocrysts plainly show the effects of pressure metamorphism. The typical gneiss consists of quartz, oligoclase, orthoclase (partly perthitic), some microcline, biotite, ilmenite, apatite, and zircon. The principal secondary minerals are chlorite, epidote, sericite, kaolin, and leucoxene. Pressure effects are plainly marked in the thin sections in granulation of the quartz and feldspar, especially the former, and the filling in of the interareas with a fine mosaic of the two minerals; and in fracturing and wavy extinction of the same minerals.

The chemical composition of the typical gneiss is indicated in analysis No. 1 on page 208. The essentially equal percentages of the alkalies, K_2O and Na_2O, and the content of SiO_2, Al_2O_3, and CaO indicate a rock of quartz monzonite character. Attention is directed to the more than appreciable amounts of TiO_2 and P_2O_5 in the analysis, each of which is above the usual average for rocks of this type—a striking feature in the composition of the rocks of the district and one which emphasizes the definite genetic relationship of the different types.

THE RUTILE-BEARING ROCK (PEGMATITE.)

The rutile-bearing rock is the most extensive of the rock types in the immediate district. (See map, fig. 18.) It is a coarsely crystalline metamorphic igneous rock composed essentially of feldspar and blue quartz with, in many places near the border portion, secondary hornblende derived from pyroxene (chiefly hypersthene), rutile, and some associated ilmenite and apatite. The ratio of these minerals is variant, but feldspar is everywhere the dominant one. The central portion of the rock mass consists almost exclusively of feldspar, usually with some quartz. Hornblende is as a rule a prominent constituent near the border portions of the rock mass and is virtually absent from the central portions. In some places quartz enters as a prominent constituent of the rock; in others little or none is visible. Its deep-blue opalescent color contrasts strikingly with that of the other minerals, and it varies from grains of almost microscopic dimensions to masses many inches across. Merrill states that at one of the openings worked by the American Rutile Company in 1902 quartz was the dominant mineral, and masses weighing several tons were procured.[a]

The textural relations of the feldspar and quartz to each other and of the hornblende where present are, over many parts of the rock

[a] Merrill, G. P., Rutile mining in Virginia: Eng. and Min. Jour., vol. 78, 1902, p. 351.

mass, similar to those of a coarse pegmatitic granite. The more feldspathic or dominant facies of the rock corresponds in chemical and mineral composition to a soda-rich syenite (laurvikose); the hornblende facies is in close agreement with granodiorite (tonalose). That the rock has been subjected to intense metamorphism is plainly shown in the granulation of the feldspar and quartz, in the partial segregation of the hornblende and rutile, and in the more or less distinct schistose structure.

Microscopic study of a large number of thin sections of the rutile-bearing rock shows the feldspar to be of several kinds—plagioclase, orthoclase, and a variant but subordinate amount of microcline. Of these, plagioclase near oligoclase is present in largest amount. It occurs usually in stout tabular individuals, the lamellæ of which are rather commonly bent and curved and in places broken across from pressure effects. Granulation and fractures are strongly marked. Much of the orthoclase is intergrown with a second feldspar, probably albite, as microperthite. The quartz, apart from its prevailing blue color in hand specimens of the rock and the abundance of hairlike inclusions of rutile, presents no unusual features. Effects of pressure are shown in the quartz similar to those in the feldspar, granulation, fractures, and wavy extinction being the most marked. The hornblende is light bluish in color and fibrous in structure, and it is clearly secondary in every section examined, being derived from pyroxene, chiefly hypersthene.

In addition to the rock-forming minerals, rutile associated with some ilmenite and in places with apatite occurs here and there as a prominent constituent, making up locally more than 30 per cent of the total rock mass. The general character and mode of occurrence of the rutile are described on a later page. In distribution the rutile, including both the pegmatite and nelsonite rutile, is essentially limited to the feldspar-quartz-hornblende rock and is confined largely to the border portions of the rock mass.

A chemical analysis, made of an average sample of the rutile-bearing rock collected from the American Rutile Company's openings near Roseland, is given on page 208 (No. 2) and will afford a general idea of the composition of the rock.

DIKES.

The district contains numerous dikes of many kinds of igneous rocks, all of which are genetically related, and with the exception of diabase nearly all gradations in composition are indicated between the extremes of the different types. Three principal types of these rocks are recognized—(1) gabbro, (2) nelsonite, and (3) diabase. Between the gabbro and nelsonite occur nearly all gradations in mineral composition, from typical hypersthene gabbro (norite) containing subordinate apatite and ilmenite to typical nelsonite containing little or none of the silicate minerals. The dikes are most abundant within the rutile-bearing feldspar-quartz rock, but they are by no means confined to it and in places are observed beyond the limits of this formation, in the outside gneiss-schist complex. They vary greatly in width, ranging up to 70 feet and more, and in many places show almost as great variation in strike, although most of them conform to a general northeast-southwest direction.

Gabbro.—The gabbro is a rock of medium-dark color and even-granular texture. The constituent minerals are feldspar and orthorhombic pyroxene, chiefly hypersthene, with subordinate ilmenite, apatite, and a little quartz, and secondary hornblende, bastite, leucoxene, and in the more altered phases, biotite. The ratio of pyroxene to feldspar varies. The feldspar is plagioclase, usually with much orthoclase. The gabbros are noticeably metamorphosed, at many localities showing well-developed schistose structure. In the more altered rocks of this type pyroxene is partly changed to secondary hornblende and bastite. With increase of the ore minerals, apatite and ilmenite, and decrease of the silicate minerals, the gabbros pass through gabbro-nelsonite into nelsonite. In some places the gabbro apparently grades into the pegmatite.

The chemical composition of a much metamorphosed schistose gabbro, occurring south of but near the American Rutile Company's mines, is shown in analysis 3 on page 208. This analysis is noteworthy for the high percentages of TiO_2 and P_2O_5, a characteristic feature in the composition of the rocks of this area that is commented on elsewhere in this paper.

Nelsonite.[a]—Nelsonite, including the several facies based on variations in mineral composition noted below, is the most abundant dike rock occurring in the district. In length the dikes range up to 2,100 feet, as exposed on the surface, and in width up to 65 feet or more, but as yet few of the dikes have been prospected in depth. Variation in mineral composition gives rise to several different facies of nelsonite, the normal one of which is an even-granular mixture composed essentially of ilmenite and apatite, with or without rutile. Except in a few places rutile is practically absent. Ilmenite or apatite may be the dominant mineral in the normal facies of the rock; probably ilmenite is dominant in most of the dikes. At several localities, notably at the General Electric Company's mines and the openings on the Bourne place, near Rose's Mill, and on the Giles tract, near Roseland, ilmenite is almost or entirely replaced by rutile, the rock being composed chiefly of rutile and apatite, with some ilmenite. Secondary hornblendes derived from pyroxene, biotite, and quartz are noted as sporadic minerals. Pyrite, partly secondary, is a constant

[a] Name proposed by the senior author. See Mineral Resources of Virginia, 1907, p. 300.

minor constituent of the rock. The ratio of titanium minerals to apatite varies, the rocks ranging from one composed largely of the dark minerals with but little apatite to one composed practically all of apatite. Magnetite replaces the titanium minerals in some of the dikes occurring in the vicinity of Lovingston, and elsewhere beyond the limits of the rutile area proper, accompanied by apatite and biotite.

The prevailing texture of the nelsonite is even granular, usually with remarkable uniformity in granularity and composition of the rock from center to walls of the dike. In places in some of the dikes there is an appearance of imperfect banding or crustification of the titanium minerals and apatite, but this is exceptional and can not be interpreted as indicating vein origin as against dike origin for these bodies. The rock is penetrated by several sets of closely spaced joints, so that it breaks into small blocks when struck with the hammer.

A second facies of the rock is observed in parts of the area, which shows a predominance of the dark ferromagnesian minerals, more especially hypersthene and secondary hornblende, over the ore minerals. This facies of the rock also contains essential feldspar, chiefly plagioclase with some orthoclase, and an occasional quartz grain. It is composed chiefly of pyroxene (hypersthene) and feldspar (plagioclase and orthoclase), subordinate apatite, and ilmenite or magnetite. In some places the pyroxene is partly or entirely altered to hornblende. For this facies of the rock the name gabbro-nelsonite is proposed.

The dikes of nelsonite, composed essentially of the ore minerals, have been prospected at many places in the area, chiefly near Roseland, Bryant, and Lovingston, for phosphate (apatite), and near Rose's Mill, on Piney River, by the General Electric Company for rutile.

Analyses of the nelsonites from this area are given on page 208 (Nos. 4, 5, and 6).

Diabase.—Diabase dikes of varying width occur in many places in the area. They are confined chiefly to the rutile-bearing rock, but are observed here and there beyond these limits penetrating the surrounding gneiss. They are fine-grained dark-colored rocks, which show under the microscope typical ophitic texture and the principal minerals plagioclase, augite, and magnetite. In common with other rocks of the area they show more or less distinct evidence of metamorphism. Analyses of the diabase are not available at this time.

CHEMICAL COMPOSITION OF THE ROCKS.

In the accompanying table are assembled, for convenience, the six analyses of the rock types found in the area. These analyses will give a fair idea of the composition of the rocks. They have been arranged in the order of decreasing SiO_2 and increasing TiO_2 and P_2O_5.

Analyses of rocks from the rutile area of Amherst and Nelson counties, Va.

[William M. Thornton, jr., analyst.]

	1.	2.	3.	4.	5.	6.
SiO_2	63.40	59.84	54.80	33.83	....	....
Al_2O_3	15.94	20.59	14.28	5.19	....	....
Fe_2O_3	2.01	.55	3.08	11.38	2.70	....
FeO	3.91	.71	7.55	15.08	29.14	1.19
MgO	1.33	.76	2.52	8.57	.50	....
CaO	3.75	4.48	6.57	8.22	16.05	21.23
Na_2O	3.53	5.23	2.61	1.28	....	....
K_2O	3.30	2.57	2.00	.50	....	....
H_2O-	.06	.18	.16	.45	} .03	.97
H_2O+	.76	.75	1.23	.75		
TiO_2	1.33	3.75	4.15	10.00	37.68	59.30
P_2O_5	.55	.35	.70	4.84	12.48	16.15
MnO	.07	.02	.02	.26	Tr.	....
CO_2	Tr.	Tr.	Tr.	....	....	....
Cl	....	....	....	.04	Tr.	....
F	....	....	....	.55	1.03	1.30
S	Tr.	....	.02	.25	1.17	.67
	99.94	99.78	99.69	101.09	100.78	100.81

1. Biotite gneiss, Roseland road, 1 mile north of Colleen.
2. Rutile-bearing feldspar-quartz-hornblende rock (pegmatite), American Rutile Company's openings, one-quarter of a mile south of Roseland.
3. Foliated gabbro, about 120 yards south of the southernmost opening of the American Rutile Company's mines, near Roseland.
4. Gabbro-nelsonite, 1 mile south of Roseland.
5. Rutile-bearing ilmenite-apatite nelsonite, General Electric Company's mines, 1½ miles northwest of Rose's Mill.
6. Ilmenite-bearing rutile-apatite nelsonite, Bourne place, 1 mile northwest of Rose's Mill.

THE RUTILE ORE.

Two distinct types of rutile occur in the district and each has been mined. In the first type, designated pegmatite rutile, the rutile occurs chiefly as disseminated grains of various sizes and in the form of wavy lines produced by dynamic metamorphism, in the coarse-grained feldspar-quartz-hornblende rock. In the second type, designated nelsonite rutile, the rutile occurs in the even-granular rock having dikelike characters and composed normally of apatite and ilmenite.

Pegmatite rutile.—The pegmatite rutile is red to reddish-brown in color, has a metallic-adamantine luster, and is remarkably pure. The rutile grains vary in size from very minute granules, almost microscopic in dimensions, up to masses weighing several pounds. The mineral is irregularly distributed through the rock, ranging from sparsely disseminated grains to aggregations which make up 30 per cent or more of the entire rock mass. Segregations of rutile in irregular wavy lines or stringers composed of disconnected rutile grains are noted in places. The rutile occurs similarly in each of the three rock-forming minerals—feldspar, quartz, and secondary hornblende—but is most abundant in the feldspar, and locally is associated with some ilmenite. So far as mining operations extend, the rutile associated with the feldspathic portions of the rock is generally free from ilmenite or other metallic minerals, but that associated with the quartz and hornblende is more likely to be mixed with ilmenite. Apatite is here and there closely associated with the rutile. Microscopic study of thin sections strongly indicates that the rutile is an original constituent of the rock in which it occurs; but in places it has undergone more or less segregation as a result of the intense metamorphism affecting the rutile-bearing rock. No evidence has been developed from either the field or the laboratory study for regarding the rutile as of secondary or subsequent origin.

Although it is prospected in a number of localities in the district, the mining of pegmatite rutile is limited to the American Rutile Company's mines on Tye River, a quarter of a mile south of Roseland.

Nelsonite rutile.—The nelsonite rutile is limited in occurrence to the dikes composed essentially or entirely of the ore minerals, ilmenite and apatite, the normal phase of the rock. The rutile-bearing dikes show all gradations in the ratio of rutile and ilmenite, from a granular mixture composed of dominant rutile and apatite with little or no ilmenite to one composed of ilmenite and apatite with or without subordinate rutile. Gradations between these two extremes are observed in the same dike. The rock with dominant rutile and apatite in a given position in the dike may gradually pass with increasing depth into a phase of the rock composed essentially of ilmenite and apatite. Accessory pyrite, in part at least secondary, is a constant constituent of the rock.

The norms calculated from the analyses (p. 208) of a representative ilmenite-bearing rutile-apatite nelsonite and of a representative rutile-bearing ilmenite-apatite nelsonite show the following percentages of the three principal minerals:

Percentages of rutile, ilmenite, and apatite in representative nelsonites.

	Rutile.	Ilmenite.	Apatite.
Ilmenite-bearing rutile-apatite nelsonite	57.9	2.6	38.3
Rutile-bearing ilmenite-apatite nelsonite	6.9	58.5	29.6

The rutile of the nelsonite dikes is uniformly darker in color, both in hand specimens and in thin sections, than the rutile of the pegmatite. Although no analyses of the two kinds of rutile occurring in the district are available at present, the darker color of the nelsonite rutile can probably be attributed to the presence of iron. In some of the workings of the General Electric Company's mines, near Rose's Mill, there occurs a series of titanium minerals containing mixtures of titanium and iron oxides ranging from rutile to ilmenite.[a] Although no analyses of this series of intermediate minerals have been made, it is probable that some of them will prove to be ilmenorutile, a variety of rutile containing up to 10 per cent and more of ferric oxide.

[a] Hess, F. L., Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 743.

Rutile-bearing nelsonite dikes have been exploited at several localities in the district, chiefly in the vicinity of Rose's Mill and Roseland. Nelsonite rutile was recently mined in the vicinity of Rose's Mill by the General Electric Company.

HISTORY OF MINING DEVELOPMENT.

Ilmenite, scattered over the surface in many places as sand and bowlders of varying size, derived chiefly from dikelike bodies by weathering, early attracted attention to the district as a possible source of iron ore. In 1878 some development work was done on the Warwick farm, where a shaft was sunk to expose one of the large nelsonite dikes outcropping on the south side of Piney River in Amherst County, but the work was soon abandoned. Further developments in the district were not attempted until some years later, when attention was again drawn to the nelsonite dikes because of their phosphate content in the form of the mineral apatite.

In 1889 considerable development work was begun in the vicinity of Bryant, on Hat Creek, and resulted in the uncovering of many ore bodies. Since 1889 considerable prospecting for phosphate (apatite) by open pits, cuts, and shafts has been done at numerous localities within the district, chiefly near Roseland, Bryant, Rose's Mill, and Lovingston. Three-quarters of a mile northwest of Roseland a number of diamond-drill holes were bored on the Giles tract to ascertain the size and quality of the apatite-ilmenite nelsonite dikes. Prior to 1907 several cars of phosphatic rock were shipped from openings on the Dillard farm, near Lovingston.

No systematic attempt was made to exploit the rutile deposits of the district until 1900, although the occurrence of the mineral was known earlier. In 1900 the American Rutile Company began operations in the pegmatite rutile on the east side of Tye River, a quarter of a mile south of Roseland, and several shipments of the ore were made to Charlotte, N. C., for concentration. In 1902 the company erected a mill at Roseland for crushing and concentrating the ore, which is mined from open cuts in the bluff near the river.

The ore, of which there is a large quantity in sight, occurs in the coarse-grained feldspar-quartz-hornblende rock (pegmatite), probably averages about 5 per cent of the rock, and is remarkably pure. The rocks on this property, as well as over the district in general, are covered by a varying depth of residual decayed rock which contains large quantities of rutile in places, especially in the soil overlying the ore bodies. Some of these residual deposits could undoubtedly be worked to advantage by hydraulic mining, as there is usually an abundance of water close at hand.

The mines of the General Electric Company were opened in 1907 on dikes of nelsonite rutile on the Warwick farm, 1½ miles northwest of Rose's Mill. The development work comprises several hundred feet of tunneling, including drifts, and two shafts, the deeper of which was sunk to a depth of 100 feet. Rutile, in association with apatite and locally with ilmenite, occurs as an original mineral in the dikes, which range in thickness up to 5 feet. In some places the rutile is very pure but of darker color than the pegmatite rutile; in others it grades by increased percentages of iron into ilmenite. Rutile has not been found on this property in the feldspar-quartz-hornblende rock (pegmatite) in deposits sufficiently segregated to be of workable grade. The ore has been mined by stoping and shipped to Allentown, Pa., for concentration.

Mining operations are in progress at present on the property of the American Rutile Company a quarter of a mile south of Roseland.

Figures for the total output of the district are not available, but since 1902 the Virginia deposits have supplied all the rutile used in this country, and much of the product has been shipped to Europe in competition with that from Norway and elsewhere.

USES OF TITANIUM.[a]

Titanium compounds have had a moderate use for many years, but it is only since the development of the high-temperature electric furnace and the discovery of rutile in workable quantities that the manufacture of titanium products on a commercial scale has become possible. Pure metallic titanium, because of its high melting point and affinity for oxygen, has found little use in the arts or industries, but alloyed with other metals and in various chemical compounds it is rapidly becoming an important element.

The products into which titanium enters as an important constituent may be classified as follows:

- Metallic alloys, such as ferrotitanium, cuprotitanium, etc.
- Incandescent media for lighting purposes, including gas mantles, arc-lamp electrodes, and filaments for incandescent electric lamps.
- Mordants and dyes for leather and textiles.
- Refractory coloring material for use in ceramics and the manufacture of artificial teeth.
- Miscellaneous.

Metallic alloys.—Titanium forms alloys with several of the metals, its alloy with iron, ferrotitanium, having the greatest commercial importance. Ferrotitanium is added to iron and steel in order to remove the oxygen and nitrogen; titanium unites with these objectionable elements to form stable compounds that pass off in the slag, the energy of combination being so great as to perceptibly raise the temperature of the molten metal. Iron and steel treated in this

[a] Compiled from various sources.

way have a freedom from blow holes and other imperfections and greater strength, elasticity, and wearing properties. Titanium steel is claimed to be especially adapted to making rails, and 35,945 tons were rolled in 1909. Cuprotitanium, an alloy with copper, is said to improve brass and copper castings in a similar manner.

Incandescent media.—The use of titanium in the metallic state or in combination with other elements to form incandescent media for lighting purposes is one of the most important that have been developed. Titanium gives a spectrum rich in lines, but it is believed that its efficiency in lamps is largely due to selective radiation and temperature effect rather than preponderance of certain colors.

Titanium compounds have been employed in making gas mantles, though not yet on a commercial scale. Incandescent lamps with filaments containing titanium are said to have been placed on the market a few years ago, but owing to the cost of production by present methods they have not become a commercial product. They are claimed to have many advantages over the ordinary lamp with carbon filaments, such as longer life, better quality of light, and higher efficiency. It is asserted that they give a greater light for the same expenditure of energy than any electric luminant hitherto known. They are not as sensitive as other lamps to variations in voltage and are able to resist high temperatures. Experiments are being conducted with the object of reducing the cost of these lamps and many patents covering methods of manufacture have been issued in the United States and foreign countries.

Arc-lamp electrodes containing titanium have been in use for a number of years and are now manufactured on a considerable scale. Experiments conducted by a large electric company are said to prove that of all substances available for use as electrodes those containing titanium give the maximum efficiency in candlepower per watt consumed. At present the most extensively used electrode containing titanium is that of the so-called magnetite arc lamp. This electrode is composed of magnetite, 15 to 20 per cent rutile, and some chromite. The magnetite gives conductivity to the electrode when cold and furnishes particles that, while not luminous in themselves, make the arc stream a good conductor; incandescent particles of rutile carried into the arc stream by the electric current give the high lighting efficiency; and the chromite is added to increase the life of the electrodes. Ferrotitanium has been used in the manufacture of electrodes and more recently titanium carbide has attracted the most attention. The suboxide of titanium has also been used. The carbide and suboxide are probably the most efficient electrodes discovered. They are, as a rule, used only for the cathodes, the anodes being made of copper or carbon.

In a carbon arc nearly all of the light radiates from the incandescent electrodes; no light is derived from the terminals of titanium electrodes, but they give a long, intensely luminous arc stream. The titanium arc lamps have a better distribution and color of light, much higher efficiency, and a lower cost of maintenance.

Mordants and dyes.—The use of titanium in the manufacture of mordants and dyes is a comparatively recent development. Titanium oxalate and titanium ammonium oxalate used with a tannin compound give a golden-yellow color of great durability and by the addition of other substances any desired shade may be obtained. Titanous chloride has been used to some extent as a mordant, and titanous sulphate is now being employed as a stripper and mordant. They yield bright, fast colors, intermediate in shade between those produced by chromium and aluminum. The double pyrosulphates of titanium and the alkali metals have recently been obtained and may be applied to textiles and other substances without injury to texture or material. The titanium oxalates and the double tartrates and lactates of titanium and an alkali metal are used in leather dyeing. Titanium ferrocyanide is employed as a substitute for the poisonous Schweinfurth green and other arsenical pigments.

Refractory colors.—In the porcelain industry rutile is used alone to impart a beautiful soft yellow color under the glaze, or with other substances to produce secondary colors. Few colors are available for underglaze painting, as they must resist the high temperatures of the kiln. The purest grades of rutile furnish the only coloring matter suitable for use in the manufacture of artificial teeth, the production of which in the United States has been estimated at 8,000,000 annually.

Miscellaneous.—Among other uses for titanium products may be mentioned the following:

Titanium sesquioxide and its salts are employed as reducing agents, sodium titanous sulphate and titanous chloride having been found most useful. Titanium dioxide is used in the manufacture of a protective paint for iron and steel. In analytical work titanium sulphate may be employed in determining the presence of fluorine. Metallic titanium and oxygen combine with great energy, producing an instantaneous dazzling light; it is used for this purpose in pyrotechnics. It has been proposed to employ the titanium nitrides as a source of nitrogen for use in fertilizers and other nitrogen compounds. Titanium readily combines with the nitrogen of the atmosphere to form nitrides, which yield ammonia on heating in the presence of hydrogen. Sometimes crystals of rutile are found sufficiently clear for gem purposes.

NOTES ON TUNGSTEN DEPOSITS NEAR DEER PARK, WASHINGTON.

By Howland Bancroft.

During a geologic reconnaissance of northeastern Washington in the summer of 1909 some tungsten prospects near Deer Park were examined. In view of the wide interest in deposits of this metal it has been thought advisable to issue a brief preliminary description of these prospects.

The properties are located in Stevens County, Wash., 30 miles a little west of north of Spokane, in the SE. ¼ sec. 16, T. 30 N., R. 42 E. This is about 10 miles almost due north of Deer Park and 5 or 6 miles northeast of Loon Lake, both of which are stations on the Spokane Falls and Northern Railway, a branch of the Great Northern Railway. There is a good wagon road from Deer Park to a point within 2 or 3 miles of the deposits, and from this point a road has been constructed to the properties.

The topography of the region is characterized by broad valleys and gentle slopes. Glacial débris is scattered over most of the mountains, and the valleys are choked with it. The country is well timbered and watered.

The deposits are located at an elevation of 3,500 feet near the head of a small gulch on the southeast side of Big Blue Grouse Mountain. A continuation of the mountain extends eastward for about a mile and forms Little Grouse Peak. These two peaks constitute the southwestern extension of the dividing range between Burnt Canyon and Ecks Creek and are a part of the Calispell Range. The top of Big Blue Grouse, the highest mountain in the immediate vicinity, is probably not over 3,800 feet above sea level; the elevation of the valley in which Deer Park and Loon Lake are located is approximately 2,200 feet.

The rocks in the vicinity of the deposits are principally arenaceous shales, probably of Paleozoic age, metamorphosed to quartz-mica schists of various colors. The original bedding planes of the rocks do not appear to have been greatly changed, being very even, with fairly uniform structure. The rocks are deeply oxidized and the various colors, from white to red and yellow, seem to be due to the amount and degree of oxidation of the iron present in the schists. The dip of the rocks is about 30° to 60° SW., and the strike is to the northwest, with many minor and in places abrupt changes in the direction of both.

A short distance to the northeast granite has been found, but no contacts of this rock and the schist were visible, so that the true relations of the two can not be positively stated. The schists are said to dip away from this granite in all directions, the granite probably being an intrusive mass.

The Tungsten King properties have been opened by two short prospect tunnels located about 50 feet apart vertically, an 80-foot inclined shaft situated 250 feet above the lower tunnel, and several shallow open cuts on various parts of the claims. The workings are scattered, and so far no large shipments have been made.

The ores occur in lenses of quartz which follow in general the bedding planes of the shales with small fissures similarly filled cutting across the country rock. A number of these quartz lenses are opened in the workings, and as exposed along the outcrop they show a thickness of 1 to 6 feet. The outcrops are largely covered by débris, but a few of the quartz lenses can be followed on the surface for a hundred feet or more.

The gangue is composed entirely of quartz, generally white, but here and there smoky and in many places iron stained.

A partial analysis of the tungsten mineral, made by R. C. Wells, of the United States Geological Survey, showed the presence of 23.9 per cent of MnO, which indicates a typical hübnerite. The crystals of hübnerite are commonly twinned and form in places along the walls of the vein in bunches over an inch thick, with smaller crystals scattered through the quartz in an irregular fashion. They are also present in most of the outcrops of the lenses. The country rock seems to be quite free from hübnerite. In general the quartz lenses are rather lean. Here and there, however, fairly massive bunches of hübnerite can be seen; the most conspicuous of these, noted in July, 1909, was at the foot of an inclined shaft where a small shoot 2 inches wide extended across the bottom of the vein for a distance of 6 feet. The quartz veins have been broken and fractured since the deposition of the minerals, and minute fissures extend across the ledges and country rock.

The other metallic minerals present are pyrite and argentiferous cosalite, of which the latter might possibly be economically important.

Although in places the hübnerite and cosalite occur together, this association is not common, the bismuth mineral, it is said, being found mainly in the lenses which are down in the gulch and not occurring in the workings high up on the hill, although there seems to be no logical reason for its absence in these outcrops. Just as the hübnerite is found scattered through the quartz, so also is the cosalite, though apparently not so generously distributed. The crystals are long and fibrous and have about the hardness of gypsum, the weathered surfaces of the bismuth mineral being rather yellow and resembling antimony oxide. A picked specimen of ore contained, according to an assay made by Ledoux & Co. for the United States Geological Survey, 27.20 ounces of silver and $2.48 in gold to the ton. A specimen of cosalite was examined by R. C. Wells, of the Survey, who transmitted the following analysis. The second column represents the analysis reduced to gangue-free basis, without moisture.

Analysis of cosalite.

Moisture	0.17	
Gangue	2.19	
Bismuth	45.25	46.44
Lead	33.66	34.54
Sulphur	16.58	17.01
Silver	.80	.82
Copper	1.16	1.19
	99.81	100.00

The above composition is intermediate between that of galenobismutite and cosalite, but nearer cosalite, whose theoretical composition is $2PbS.Bi_2S_3$ (S 16.1, Pb 41.8, Bi 42.2). Galenobismutite has the formula $PbS. Bi_2S_3$ (S 17.08, Pb 27.6, Bi 55.40). Mr. Wells thinks it doubtful if the molecular ratio has any definite meaning in minerals of this character and says: "Possibly the two sulphides, PbS and Bi_2S_3, are capable of forming solid solutions of one in the other, or have been precipitated together from a state of colloidal solution."

Pseudomorphs of hematite and limonite after pyrite are present in large numbers in the wall rock and in the quartz lenses. These crystals vary from those of microscopic size to 2-inch cubes, the pyrite being in all stages of alteration. In places the pseudomorph itself is nearly decomposed and only the skeleton of the crystal remains. These cubes are developed on a larger scale in the vein than in the wall rock and seem to extend only a foot or so into the inclosing walls. In the immediate vicinity of the quartz ledges the country is locally silicified and highly stained with iron oxides.

The origin of the deposits is probably due to the waters which accompanied the intrusion of the granitic rock a short distance to the northeast.

Considering the scattered character of the ore and the haul of 10 miles to the railroad station, it is possible that concentration at the property might be advisable.

SURVEY PUBLICATIONS ON ANTIMONY, CHROMIUM, MONAZITE, NICKEL, PLATINUM, QUICKSILVER, TIN, TUNGSTEN, URANIUM, VANADIUM, ETC.

The principal publications by the United States Geological Survey on the rarer metals are those named in the following list.

These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Publications marked "Exhausted" can not be procured from the Government. No publications on Alaskan occurrences are listed here.

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Iron and Manganese.

SOME IRON ORES OF WESTERN AND CENTRAL CALIFORNIA.

By E. C. Harder.

INTRODUCTION.

Iron-ore deposits are abundant in different parts of California, yet until very recently no ore had been mined from them. The only iron-ore furnace in the State is an experimental Heroult electric furnace installed in 1907 by the Noble Electric Steel Company at Heroult, on Pit River, Shasta County, and operated intermittently in 1907, 1908, and 1909. During 1909 a commercial furnace was erected. The ore used is mined in the vicinity of the plant. Besides the Noble furnace there are only four iron-ore furnaces in the Western States—the Minnequa coke furnaces at Pueblo, Colo., consisting of six stacks; the Irondale charcoal furnace at Port Townsend, Wash., consisting of one stack; the Black Sand and Gold Recovery Company's electric furnace at Hood River, Oreg., and the Oswego charcoal furnace at Oswego, Oreg., consisting of one stack. The Oswego furnace has not been active since 1894 and the electric furnace at Hood River is only in an experimental stage. The Pueblo furnaces, however, have been operated regularly for many years, their ores being obtained largely from Wyoming, Colorado, and New Mexico. The furnace at Port Townsend has been active intermittently, its ores coming from Texada Island, British Columbia, and from Washington. No California ore has been used in any furnace outside of the State.

The principal iron-ore deposits of California are the Pit River or Redding deposits, Shasta County; the Gold Valley deposits, Sierra County; the Minaret deposits, Madera County; the Iron Mountain, Cave Canyon, Providence Mountain, and Newberry deposits, San Bernardino County; and the Eagle Mountain deposits, Riverside

County. Of minor importance are the Patamocas or Beegum deposits, Tehama County; the Newtown and Indian Springs deposits, Nevada County; the Hotaling deposit, Placer County; the Detert deposit, Calaveras County; the Mount Raymond deposits, Madera County; the Perfumo Canyon deposit, San Luis Obispo County; and the Owl Holes, Kingston Range, Garlic Springs, and Iron Age deposits, San Bernardino County. Numerous other small deposits are known.

The Minaret deposits, situated near the summit of the Sierra Nevada, are said to be the largest in California and perhaps in the West. Of nearly equal size are the Eagle Mountain deposits, located near the boundary of the Mohave and Colorado deserts; all the rest of the deposits are much smaller. The only ores which have been worked with the intention of producing pig iron are the Hotaling deposit, operated some years ago unsuccessfully on account of the high cost of fuel, and the Pit River deposits, operated intermittently for the last few years to obtain ores for use in the Noble electric furnace. Practically, therefore, the iron ores of California are untouched.

The Eagle Mountain and Iron Age deposits, which were examined and mapped in detail during the summer of 1909 by the writer, with the assistance of John L. Rich, are the subjects of special reports. The Perfumo Canyon and Hotaling deposits and the iron ores of Calaveras County were examined briefly by the writer during the fall of 1909 and are herein described.

PERFUMO CANYON DEPOSIT, SAN LUIS OBISPO COUNTY.

The Perfumo Canyon iron-ore deposit is in San Luis Obispo County, about 5 miles south of west from San Luis Obispo, in the San Luis or Los Osos Mountains. It consists of a nearly vertical bed of limonite interlayered with dark shale and sandstone of the Franciscan formation (Jurassic). The bed strikes in general a little north of west and is said to be traceable for more than a mile,[a] but was followed by the writer through only about half of its extent. Its thickness varies from 8 to 12 feet.

Perfumo Canyon has a northeast-southwest direction where the iron-ore bed crosses it, the latter striking nearly east and west at this point but changing in direction to north of west as it runs up the hills on both sides. The principal outcrops are found where the bed crosses the creek, and where it crosses the road several hundred feet to the northwest, but smaller exposures occur to the north-

[a] Fairbanks, H. W., San Luis folio (No. 101), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 14; Structural and industrial materials of California; Bull. California State Min. Bur. No. 38, p. 301.

west and southeast of these. The slopes of the valley are very gradual and the trend of the ore outcrops is the same as the general strike of the bed. Perhaps several hundred feet northeast of the ore bed lies the contact of the Franciscan formation with serpentine.

Where it outcrops on the creek, the bed is about 9 feet wide, strikes N. 65° W., and dips 68° S. North of it are dark grayish-brown interbedded coarse and shaly sandstones, the latter very ferruginous, especially near the ore. The contact between the sediments and the ore is well defined, however, and in places a few inches of soft ferruginous earth occurs along it. South of the ore bed the contact is not so well marked, the ore grading into dark ferruginous shaly sandstones which contain considerable iron within a foot from the contact. The shaly sandstones are broken up into small rounded blocks by numerous fractures. Within the ore bed are several beds or lenses of ferruginous shaly sandstone, varying up to 6 inches in thickness and extending along the ore bed for distances of 8 or 10 feet. The strike of all these lenses is parallel with the strike of the ore bed and the inclosing sediments. Their contact with the ore is sharp. The ore itself has a bedded structure, the beds ranging in thickness from a few inches to a foot and a half. The different beds are finely laminated parallel to the bedding planes.

On the roadside the ore bed is exposed in a cut. It is here about 11 feet thick, strikes N. 80° W., and dips 60° S. The component beds vary greatly in thickness, as in the exposure at the creek, the thick beds generally being made up of dark-brown glossy laminated ore, whereas in the thin beds the ore is somewhat mixed with shaly and sandy material. The bedding planes and laminations are very prominent throughout the bed. On both sides of the ore are beds of soft dark-brownish sandstone broken into blocks. The fracture planes are coated with limonite, but little replacement has occurred and the contact between ore and sandstone is usually sharp.

On the hillside several hundred yards east of the exposure in the creek a trench shows the ore bed to have a thickness of about 11 feet. Here also it is bounded on both sides by dark sandstones.

The ore is largely a dark-brown or black glossy limonite finely banded and laminated parallel to the strike of the bed. At some places the lamination is hardly visible, but at others it is strongly pronounced because of thin bands of yellow ocher interlayered with the dark glossy ore. These bands are rarely more than a millimeter thick, and are generally mere films separating thicker laminæ of dark ore. Numerous fractures run through the bed, so that the ore breaks up into small variously shaped blocks with plane surfaces. This condition is characteristic of the bed throughout its extent.

The following are analyses of the ore and the highly ferruginous shaly sandstone.

Analyses of iron ore and wall rock from Perfumo Canyon, California.

[Dickman & Mackenzie, analysts, 1120 Rookery Building, Chicago.]

		Iron.	Phosphorus.	Silica.
1	Ore outcrop near creek, 11 feet of ore	44.80	0.500	15.41
2	Ore outcrop 2,000 feet southeast of No. 1	47.60	.530	11.20
3	Ore outcrop 3,000 feet northwest of No. 1	46.10	.510	13.10
4	3 feet of ferruginous shale underlying No. 1	16.30		
5	Ferruginous shale, average	13.30		
6	Ferruginous shale, selected	13.40		

MIXTURE OF SAMPLES 1, 2, AND 3.

Iron	46.16	Magnesia	Trace.
Silica	13.23	Manganese	0.20
Phosphorus	.513	Sulphur	.639
Alumina	1.42	Titanic acid	None.
Lime	6.00		

The analyses show that the ore is high in phosphorus and silica and low in iron.

It seems clear that the iron ore of Perfumo Canyon is an original sedimentary deposit formed during an interval in the deposition of the inclosing sandstones and shales. The character of the ore, the bedding and fine laminations, and the included sedimentary beds all point to this conclusion. It is probably of the nature of a bog deposit which has been consolidated during the compression and folding of the accompanying strata. Accepting this as the origin of the ore, we may make conjectures as to the depth to which the bed is likely to extend.

The ore may have been deposited in a circular basin with a probable diameter of 5,000 feet or more, which is the present length of the deposit, or in an elliptical basin with one diameter of 5,000 feet or more. Subsequent erosion after tilting has removed a large part of the bed. If it is considered that the deposit was originally circular in outline and that about half of it has been eroded, the vertical bed as it remains would have a depth of 2,500 feet or more at the center and would gradually decrease in depth toward the ends. On the assumption that the bed has a fairly regular thickness of 10 feet there would in this case be a great tonnage of low-grade ore left in the ground. However, the bed may have been originally elliptical instead of circular in outline, and if so the quantity of ore is uncertain within a wide range, depending on whether the larger diameter is horizontal or vertical. Another uncertain factor is introduced by the fact that either more or less than half the bed may have been eroded. These conjectures show the possibilities in a continuous though thin ore bed. For commercial purposes, however, it must be considered that the bed may vary in thickness beneath the surface, may pinch out altogether for long distances, or may grade into ferruginous sandstones at slight depths. A depth greater than 100 feet should not be assumed without exploration, and this would reduce the probably available quantity to a few hundred thousand tons of low-grade ore, which is a fairly safe commercial estimate.

IRON ORES OF CALAVERAS COUNTY.

Several small deposits of brown iron ore occur in Calaveras County as replacements in slate or schist. They are in the central portion of the Mother Lode district, in the western foothills of the Sierra Nevada. About 50 or 60 miles northeast is the summit of the Sierra; about 15 miles west is the edge of the Sacramento and San Joaquin valley. There is a gradual increase in relief from the great central valley of California toward the summit of the Sierra. In the area under discussion there is a difference in elevation of about 1,500 or 2,000 feet between the valley bottoms occupied by the larger streams and the general level of the tops of the foothills. Above this level, however, rise several higher ridges, such as the Bear Mountains, due doubtless to the resistant nature of the rocks composing them. The hills are covered with sparse forests of digger pine, live oak, and white oak, with here and there open grassy areas, cultivated fields, and brush-covered slopes. Yellow pine and sugar pine begin to appear in the eastern part of the area and increase in number toward the summit of the range.

There are three localities at which iron ores are known in Calaveras County, 1½ miles northeast of Valley Springs, half a mile north of Esmeralda, and 1 mile north of Murphy. All the bodies are small and consist of low-grade ore, so that they are of little or no commercial importance.

The occurrences of iron ore northwest of Valley Springs, the principal one of which is known as the Detert deposit, are replacements in a slaty rock mapped by Turner [a] as amphibolite schist (earlier than late Cretaceous); those near Esmeralda and Murphy are in the Calaveras formation (Carboniferous).[b]

The Detert deposit shows several irregular outcrops of iron ore scattered over an area 100 feet wide and 200 or 300 feet long on the top and slopes of a small knoll. The knoll, consisting of yellow and light-brown and red schist (amphibolite schist), juts southward from a slightly higher transverse ridge on which a capping of white, yellow, and reddish sandstone and conglomerate (Ione formation of Tertiary age) overlies the schist. North and northwest of this ridge the schist reappears and contains several scattered iron-ore and ocher

[a] Turner, H. W., Jackson folio (No. 11), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

[b] Turner, H. W., and Ransome, F. L., Big Trees folio (No. 51), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

deposits. Closely associated with the amphibolite schist are bands of Mariposa slate (Jurassic). Auriferous gravels occur locally.

The largest ore body in the Detert deposit is 40 or 50 feet long and about 6 feet wide. It rises to a height of 15 feet above the general level of the knoll, on the summit of which it occurs in decomposed, sandy, ferruginous red, yellow, and brown schist. Five or six smaller bodies are present close by, ranging from a few feet to 20 feet in length and up to 3 feet in width. The slaty structure strikes approximately N. 35° to 45° W. and dips very steeply to the southwest. Owing to the great deformation and decomposition which the schist formation has undergone the bedding is practically obliterated. Most of the ore lenses strike and dip parallel to the schistosity, but some are irregular in structure.

The horizontally bedded sandstones and conglomerates of the Ione formation on the ridge to the north are in places deeply stained with iron in the lower part. They rest on the upturned edges of the schist. The iron-ore lenses in the schist area north of the strip of Ione formation are mostly of small extent, being between 5 and 10 feet in length and up to 2 feet in width. Several larger deposits, however, 30 or 40 feet long and 6 to 8 feet wide, occur on a ridge to the northwest. The smaller masses are generally parallel to the bedding; the large ones are irregular.

The ores are brown ores, commonly known as limonite or brown hematite. They are of two varieties—a dark-brown or black glossy ore and a lighter-colored, more earthy ore. The former was doubtless deposited in open spaces, such as cavities or fissures; the latter is clearly a replacement of the schist, the structures of which are in places preserved in great detail. Locally the schist is only slightly replaced, and from this there are all gradations to solid ore. Much of the earthy ore occurs as fragments separated by veins and masses of black glossy ore. The deposits have apparently originated by the infiltration of iron oxide from above, which replaced the schist and filled fissures and cavities in it.

North of Murphy there are several small exposures of brown iron ore occurring as replacements and fissure fillings in the quartzite and slate of the Calaveras formation (Carboniferous). The best known of these is the Big Trees or Sperry deposit, located on the north side of a narrow, deep canyon about 1 mile north of Murphy. The rocks of the north canyon wall consist largely of brown, iron-stained quartzite and chert with a small lens of limestone near the base. The quartzite is much fractured and brecciated along the canyon slope above the limestone, and in some of these fractures there are small infiltrations of iron ore. Three tunnels have been driven into the hill; two on the lower slope encountered some ore, but the third, about 90 feet in length, driven into the face of a quartzite cliff halfway up the slope, encountered nothing but iron-stained quartzite and chert. Surface fragments of iron ore are abundant, however, along the crest and slope of the ridge.

Other iron-ore showings occur on the land of Price Williams, about one-fourth and one-half mile southeast and 1¼ miles west of the Big Trees deposit. At these localities no development work has been done and the ore appears only in surface outcrops and fragments of float. The Esmeralda iron-ore occurrence is also in the Calaveras formation and is very likely a western continuation of the Murphy belt of deposits.

The Murphy and Esmeralda deposits were doubtless formed by deposition of hydrated iron oxide from iron-bearing waters percolating downward along a fractured zone in the quartzite. The waters penetrated the quartzite and stained it, but little or no replacement has occurred. The ore deposited in cavities is largely of a dark-brown glossy variety but some yellowish ocherous ore occurs. The iron was probably derived from beds which originally overlay the quartzite, but have since been eroded.

HOTALING DEPOSIT, PLACER COUNTY.

The Hotaling iron-ore deposit is 6 miles north of Auburn and 3½ miles northwest of Clipper Gap, Placer County. The workings, consisting of several trenches, pits, and shafts, are on a small wooded knoll extending southwestward from a higher ridge. One shaft has an engine house in connection. Ore was mined and smelted here some years ago and considerable ore is still in the dumps.

A band, perhaps several hundred feet wide, of fine-grained basic igneous rock, probably diabase, crosses the knoll in a northwest-southeast direction. Northeast of it, forming the higher ridge, is a mass of granodiorite;[a] to the southwest, on the slope of the knoll, are sediments of the Calaveras formation (Carboniferous), here largely quartzite, but elsewhere composed of quartzite and slate with local limestone lenses. The granodiorite is later than the diabase, and both are later than the Calaveras formation. The iron ores occur at the contact of the diabase and the quartzite and within both formations, though more generally in the diabase. The ore is magnetite, both fine grained and coarse grained, and with it are associated a large number of minerals, such as garnet (andradite), epidote, pyroxene (augite), amphibole (anthophyllite), calcite, pyrite, chalcopyrite, and quartz. Garnet, epidote, augite, and anthophyllite are very abundantly developed in the diabase, but sparingly in the quartzite. Magnetite, quartz, calcite, pyrite, and chalcopyrite occur both in the diabase and in the quartzite.

[a] Lindgren, Waldemar, Sacramento folio (No. 5), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

The workings extend along the contact of the quartzite and diabase through a distance of 150 or 200 feet, and the extent of the ore beyond this in either direction is problematic. The width of the contact zone is probably about 50 to 75 feet. Some distance northwest of the workings, near the diabase contact, is a small area of limestone. It is possible that the quartzite at the workings is really a silicified limestone metamorphosed by the igneous rock. Its present texture is typically that of a fine-grained quartzite, in which, however, there are numerous veinlets of calcite and quartz, impregnations of magnetite, and small amounts of metamorphic minerals near the diabase.

From an examination of various specimens of contact material it appears that the minerals have been formed in the following order: Andradite, magnetite, augite, pyrite, chalcopyrite, anthophyllite, epidote, quartz, calcite, limonite. Andradite, magnetite, and augite, the typical metamorphic minerals, occur both along the contact zone and in the wall rock; to a small extent within the quartzite and to a larger extent within the diabase. The andradite is generally in coarse crystals or masses up to an inch or two in diameter; the magnetite and augite are mostly in small crystals and granular aggregates. In many places small veins of magnetite cut through garnet masses. Augite is intimately associated with the magnetite, either intermixed with it as fine grains or contained in it in small irregular masses. Pyrite and chalcopyrite are disseminated through the magnetite and also occur within the quartz and calcite veins cutting the metamorphic minerals. Anthophyllite is found in dark-green fibrous aggregates in calcite and quartz associated with the metamorphic minerals. Epidote is associated with calcite in veins in the diabase. From their association it appears that epidote crystallized first. Quartz and calcite occur in veins cutting the metamorphic minerals and wall rocks. Quartz is apparently rare in the diabase, but calcite occurs abundantly in both diabase and quartzite. Calcite veins cut quartz veins, and quartz in turn is deposited in the center of calcite veins. Chalcopyrite is common within both quartz and calcite veins. Limonite occurs at the surface as an alteration product of magnetite, pyrite, and ferromagnesian minerals.

Most of the ore is thoroughly intermixed with the metamorphic minerals and later vein minerals and is therefore of low grade. Locally, however, there are masses of clean and apparently high-grade ore. It is either coarsely crystalline or finely granular; no massive, glossy ore, so common in many magnetite deposits, occurs. The ore body is small and as a whole of low grade.

The nature of the ore and the presence of metamorphic minerals point to the fact that the ores originated from a deep-seated source.

Their occurrence at the contact of the quartzite and diabase would indicate that the solutions were derived from the diabase. This view is further strengthened by the fact that the contact minerals are very abundant near the quartzite contact and probably absent or at any rate much less abundant near the granodiorite. It is nevertheless possible that the solutions have originated from the large granodiorite mass and have come up along the diabase-quartzite contact. It is also possible, as has been intimated, that the present quartzite was originally limestone and that solutions from the granodiorite have broken through the diabase and have replaced the much more readily altered limestone. Whatever the original source of the solutions may be, the ore has been deposited along the diabase-quartzite contact and has partly replaced the quartzite, while the metamorphic minerals associated with the ore occur largely along the contact and in the diabase near it.

THE IRON AGE IRON-ORE DEPOSIT, NEAR DALE, SAN BERNARDINO COUNTY, CALIFORNIA.

By E. C. Harder and J. L. Rich.

INTRODUCTION.

During the summer of 1909 the writers examined and mapped in detail the Iron Age iron-ore deposit, near Dale, San Bernardino County, and the iron ores of the Eagle Mountain district, in northern Riverside County, Cal. The former is the subject of the present discussion; a separate bulletin is being prepared on the latter. The writers are indebted to Dr. A. C. Spencer for many helpful suggestions in the preparation of this paper.

Dale, so named from the Virginia Dale gold mine near it, is a mining camp of about half a dozen houses just north of the boundary between San Bernardino and Riverside counties. (See fig. 19.) It is connected with Amboy, on the Atchison, Topeka and Santa Fe Railway, by a stage road 45 miles long with biweekly service, but it can also be reached from Mecca, on the Southern Pacific Railroad. Dale is the only town in this part of the Mohave and Colorado deserts between the two transcontinental lines.

LOCATION AND GEOLOGY.

The Iron Age iron-ore deposit is 6 miles east of Dale and a mile or two north of the boundary line between San Bernardino and Riverside counties, in a barren desert region. It is located in the eastern part of a range of bare mountains extending east and west along the boundary line and connected by an area of low hills with the Pinto Mountains to the southeast. To the north and south of this range are broad, flat desert areas, beyond which lie other mountain ranges. To the south can be seen the Eagle Mountains, in which the largest iron-ore deposits of southern California occur. To the north are the Sheep Hole Mountains, beyond which is the main line of the Atchison, Topeka and Santa Fe Railway.

The deposit may be reached from Dale by a direct trail through the mountains or by a circuitous wagon road along the edge of the desert area to the north, a distance of 10 or 12 miles. The Dale pumping station, about 6 miles north of Dale, is the nearest watering place, and there is no other spring or well within a radius of 20 miles.

The mountain range in which the iron ores are located consists of intrusive dioritic, granitic, and syenitic rocks of varying texture—

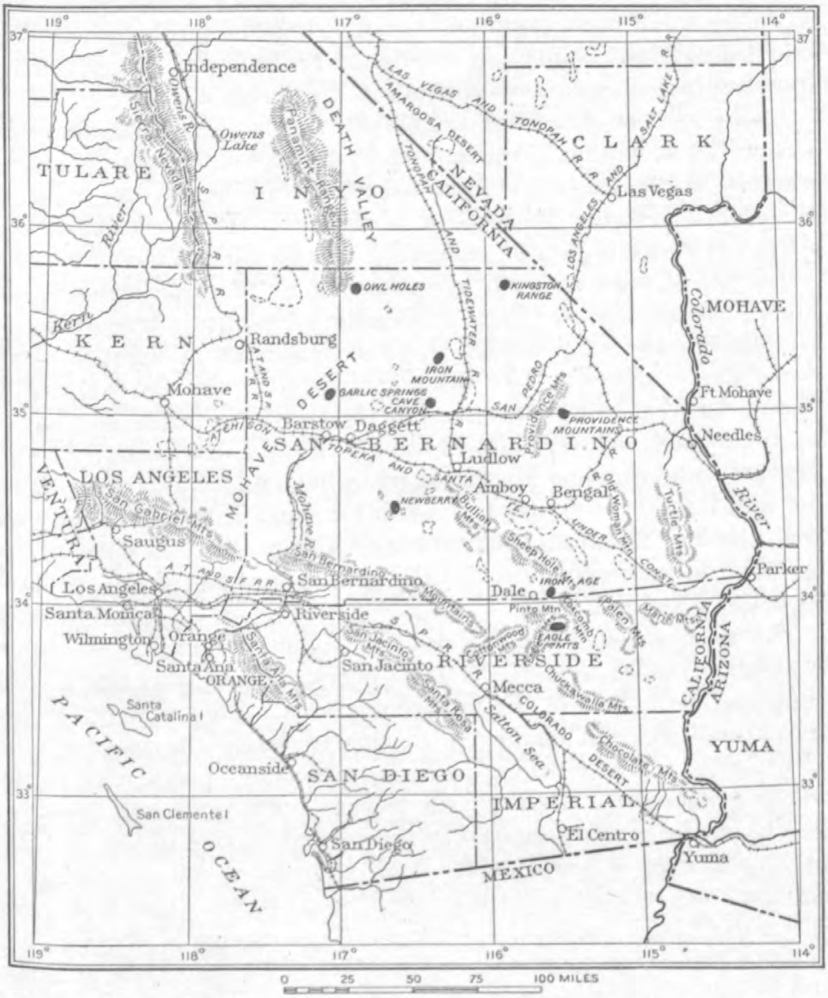


FIGURE 19.—Map of portions of southern California, Nevada, and Arizona, showing location of iron-ore deposits in Mohave and Colorado deserts.

granitic, porphyritic, and aphanitic. In the southern part of the Pinto Mountains metamorphosed sediments are associated with these rocks, but elsewhere no sediments occur.

Nothing is known of the age of the rocks except that the igneous rocks are younger than the sediments. Except in one small area, the formations of the southeastern Mohave and Colorado deserts have never been examined with the view of correlating them with rocks of known age in adjacent regions in California, Nevada, and Arizona. To the writers' knowledge no fossils have ever been found in any of the metamorphosed sediments of the region, and they have generally been supposed to be of pre-Cambrian age. The intrusive rocks have been thought to be much younger, some possibly as late as Tertiary. The one small area examined lies a few miles northwest of Siam, San Bernardino County, on the Santa Fe Railway. Here Darton [a] found unmetamorphosed sediments of Cambrian age.

Geologic work has been done recently by Lee,[b] Schrader,[c] and Bancroft [d] in western Arizona and by Mendenhall [e] in the San Bernardino Mountains and at scattered localities between that range and the Imperial Valley in southern California. The rocks of western Arizona consist of granite, gneiss, schist, and various metamorphosed sediments of pre-Cambrian age intruded by Mesozoic, granitic, and dioritic rocks and overlain by Tertiary rhyolites, trachytes, and andesites, Quaternary basalt, and unconsolidated or slightly consolidated desert deposits. To the northeast the Paleozoic rocks of the Grand Canyon section overlie the pre-Cambrian rocks and extend northward and eastward into Nevada, Utah, and northeastern Arizona. The pre-Cambrian and associated rocks have been followed by Schrader and Bancroft westward to a point a short distance beyond Colorado River. The Iron Age iron-ore deposit is about 65 miles west of the river in a straight line, but the rock formations of the two areas have not been connected.

The area of Mendenhall's work in the San Bernardino Mountains is about 60 miles west of the Dale region, and on this side also no work has been done in the intervening area. The rocks of the San Bernardino and San Jacinto mountains are largely intrusive granitic and dioritic rocks belonging perhaps to the same period of intrusion as the granodiorite of the Sierra Nevada. On the north slope and locally on the south slope and in the central portion of the San Bernardino Range are sediments of all degrees of metamorphism of unknown age, though older than the igneous rocks. Metamorphosed sediments, largely schists, older than the sediments of the San Bernardino Range, occur in the eastern part of the San Gabriel Range and in places in the eastward extension of the San Bernardino Moun-

[a] Darton, N. H., Discovery of Cambrian rocks in southeastern California: Jour. Geology, vol. 15, 1907, pp. 470-473.

[b] Lee, W. T., Geologic reconnaissance of a part of western Arizona: Bull. U. S. Geol. Survey No. 352, 1908.

[c] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. U. S. Geol. Survey No. 397, 1909.

[d] Bancroft, Howland, Reconnaissance of the ore deposits of central western Arizona: Bull. U. S. Geol. Survey (in preparation).

[e] Mendenhall, W. C., unpublished notes.

tains and in the Cottonwood, San Jacinto, and Santa Rosa mountains. Locally on the lower slopes of the ranges there are slightly consolidated sediments of late Tertiary or early Pleistocene age.

The sediments examined by Darton consist of a series of shales, limestones, sandstones, and quartzites of Cambrian age resting on a basement of granite. The area is about 40 miles north of the Iron Age deposit, and the intervening mountain ranges are made up largely of igneous rocks.

In the Eagle Mountains, Palen Mountains, and neighboring ranges the writers found metamorphosed sediments, schists, and gneisses, intruded by a great variety of igneous rocks. No fossils were found in any of the sediments.

The Iron Age iron ores are largely hematite altered from magnetite, in the form of veins cutting intrusive granite and granite porphyry. Metamorphic minerals, chiefly garnet and epidote, are locally associated with the ore and rocks. The principal iron-ore veins occur over an area about half a mile square, the larger veins, on account of their resistant nature, forming the summit of a large hill. Several small veins occur in the area between the Iron Age deposit and Dale. The ores are very pure and of high grade, but the veins are not of sufficient extent to make the deposit very attractive commercially.

DESCRIPTION OF THE INTRUSIVE ROCKS.

GENERAL STATEMENT.

There are two fairly distinct rock types associated with the Dale iron-ore deposit, though in the field no sharp lines can be drawn between them. In fact there is as much difference in general appearance between different phases of the same type as there is between the two main types. One type is an augite-soda granite with feldspars entirely albite or albite-oligoclase and a texture in general granitic or coarsely porphyritic. The other, which is distinctly and characteristically porphyritic, may be called augite granite porphyry. It differs mineralogically from the granite in that its predominating feldspar is orthoclase and that only subordinate amounts of albite are present. There is a marked variation in texture within each of these two types, but the general structure of each type remains characteristic, and the characteristic feldspars remain constant, though there is apparently a variation in the relative proportion of orthoclase and albite in different phases of the granite porphyries. The chemical difference between the two types as shown by the mineral composition consists in the absence of potash in the granite and the presence of both soda and potash in the granite porphyry.

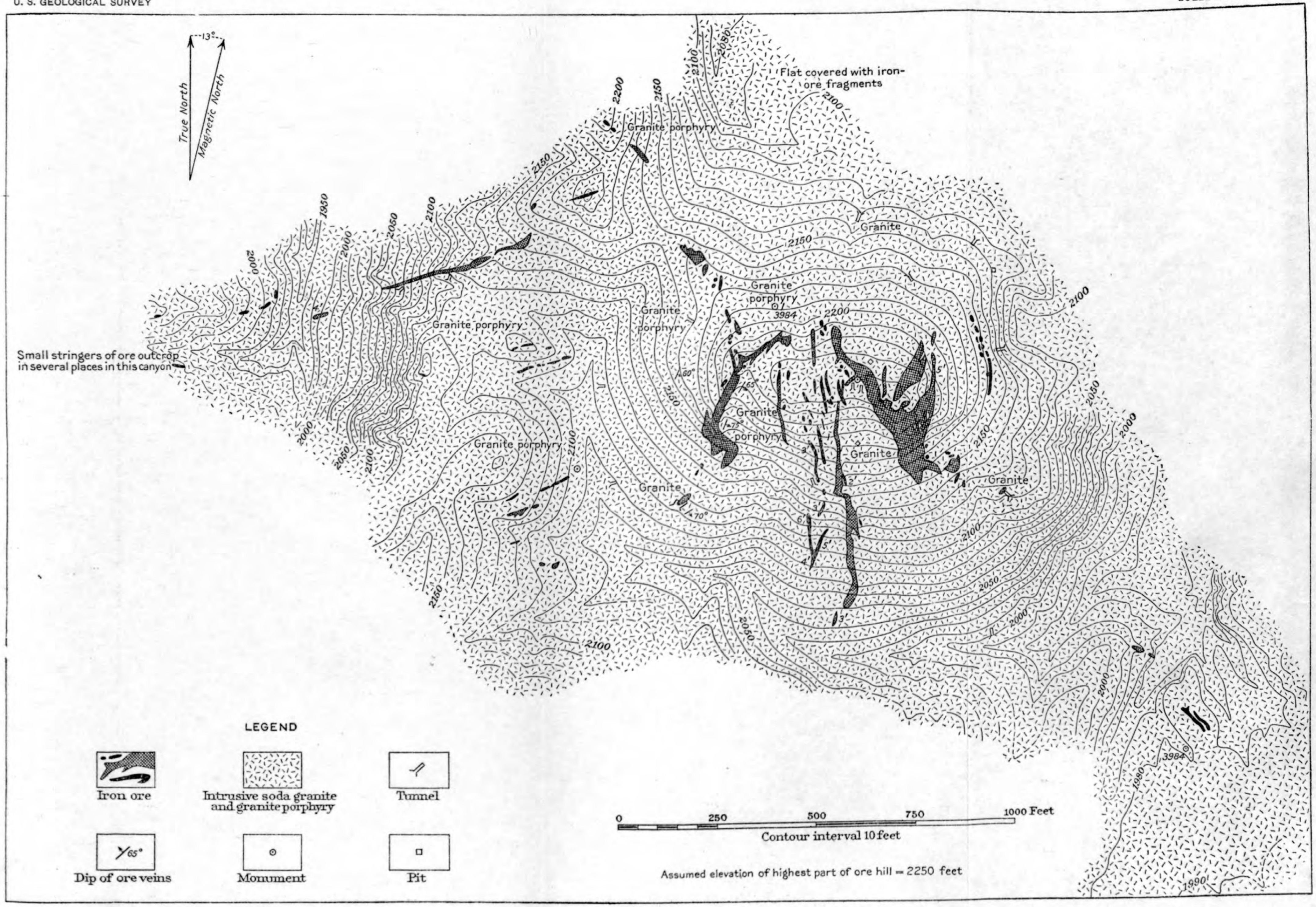
Quartz is present in both types, in approximately the same proportions. The augite in all the rocks is decidedly subordinate in amount. Most of it is partly and some of it entirely altered to green hornblende or chlorite. Locally all that remains to show the former presence of augite is a considerable development of secondary green hornblende, in which there is an occasional augite core. A small amount of biotite is present.

DETAILED DESCRIPTIONS.

Granite.—Rocks of the granitic type rich in soda are generally distributed on the east and south sides and top of the hill, and occur also in places on the west and north sides. (See Pl. II.) In the hand specimen they show in general a medium-grained granitic to coarsely porphyritic texture. Cloudy white feldspars, some of them considerably epidotized, quartz, and a ferromagnesian mineral of a light-green color may be seen with the hand lens. The porphyritic phases are simply portions where certain minerals have grown larger than those surrounding them. The groundmass remains of about the same texture as in the granitic type and with the unaided eye is easily seen to be well crystallized.

Under the microscope the rock of this type shows large phenocrysts of albite embedded in a medium-grained groundmass of albite and albite-oligoclase, quartz, and augite. Many of the albite phenocrysts show resorption boundaries. Micropoikilitic intergrowth of quartz and albite is very common and well developed. The quartz also occurs in good-sized phenocrysts, many of which were evidently early crystallizations of the magma, for they show considerable resorption. It is a very important constituent of the rock, making up nearly one-third of its mass. Augite is nearly all altered to green hornblende, though a few unaltered cores remain. There is also a little secondary biotite. The accessory minerals include apatite, sphene, a little magnetite, and scattered crystals of zircon. Apatite is abundant and represents one of the earliest crystallizations. Sphene is very abundant in all the rocks of this area. Epidote is plentiful, both in small anhedrons within the feldspar phenocrysts and as larger masses scattered through the rock. All the slides examined show occasional irregular masses of calcite.

Granite porphyry.—The porphyritic rocks are abundant in the western part of the iron-ore area and occur locally in the northern and southern parts. The most typical phase of the rocks thus classed together shows in the hand specimen large phenocrysts of a pink feldspar, many of them nearly an inch in diameter, embedded, together with smaller phenocrysts of a clear or cloudy white feldspar and a partly altered ferromagnesian mineral, in a very fine grained felsitic groundmass, too fine for the components to be seen with a hand lens. This groundmass has a gray to greenish-gray or pink color,



DETAILED MAP OF THE IRON AGE IRON-ORE DEPOSIT NEAR DALE, SAN BERNARDINO COUNTY, CAL.

varying in different specimens. In all it shows the felsitic character which serves to distinguish it from the porphyritic phase of the associated granite, though there is as much variation in general appearance within both the granites and the porphyries as there is difference between them.

Different specimens show great variations in the development of the phenocrysts. The most common phase, that with the large pink feldspars, has already been described. Another shows pink and white feldspar phenocrysts of about equal size and comparatively small (few of them reaching a quarter of an inch in diameter) in a similar felsitic groundmass. Still another is very fine grained and has very small phenocrysts, mostly of the clear white or colorless feldspar (albite).

Under the microscope all these phases exhibit practically the same composition, but even in different parts of one thin section there may be distinct variation in the development of phenocrysts. In the typical porphyritic variety the large phenocrysts are orthoclase and the smaller phenocrysts are quartz and albite with here and there an augite still unaltered. The groundmass is a very fine mosaic of quartz and orthoclase. The large phenocrysts of orthoclase and quartz show marked embayments, due to partial resorption by the magma. This is especially noticeable in the quartz.

Other phases have smaller phenocrysts of orthoclase and albite, both of approximately the same size, with similar development of quartz and remnants of augite and with a groundmass similar to that just described. Still others have smaller phenocrysts of all minerals and a groundmass made up of finely crystalline orthoclase with most of the quartz separated as small phenocrysts.

The augite is largely altered to chlorite and green hornblende, with a little secondary biotite. In a few cases good-sized augite cores, or even whole crystals, remain.

The accessory minerals of the porphyries are the same as those of the granites—abundant apatite and sphene, with a little calcite and considerable epidote.

PROBABLE RELATION OF THE GRANITE AND GRANITE PORPHYRY.

As the two rocks just described show no definite boundaries or contacts, and as they are in many respects essentially similar, they might be looked upon as pertaining to the same intrusion were it not for the fact that one has orthoclase as an essential constituent while the other contains none at all. If there were merely variations in the amount of potash in different parts of the intrusion, the relations might be explained as the result of segregation in the cooling mass; but in this case segregation may hardly be supposed to have gone so far as to remove all potash from a large part of the cooling intrusive body.

The moderately coarse granular texture of the granites, as contrasted with the distinctly porphyritic texture of the granite porphyries, indicates that the latter cooled more quickly than the former and hence must have been introduced at a different time. The granite porphyry was probably intruded into cold rocks and cooled quickly, while the granite was later intruded into the hot porphyry. The fact that there are no sharp contacts indicates that the porphyry was not entirely consolidated at the time of the intrusion of the granite.

From the above-stated considerations it is thought that the soda granites are the result of the intrusion and mixing into the partly consolidated granite porphyries of a magma containing no potash, but otherwise similar to that of the granite porphyries. The granitic rocks may possibly have been derived from the same parent magma as the porphyritic rocks, their variation in composition from the latter being due to differentiation, but more probably they were derived from an entirely different source.

METAMORPHISM AND WEATHERING.

The metamorphic changes that have taken place in the rocks since their intrusion are mostly of such a nature that they may be best explained as due to the effects of solutions which permeated the rocks at the time of the introduction of the ores, the alteration occurring under deep-seated conditions. The principal metamorphic changes are the alteration of augite to secondary products, the development of epidote, and the introduction of the ores. The alteration of the augite has resulted in most places in the formation of secondary green hornblende, and in some places of chlorite. Associated with the altered augites are notable quantities of sphene, which is in places grouped in bunches around the augite cores. The association suggests the derivation of the sphene from an augite containing a little titanium. Some of it may be an original constituent of the rock, but certainly not all.

The epidote is probably a product of this hydrothermal metamorphism. It occurs either in irregular grains scattered through the rock or as distinct veins. The feldspars of the igneous rocks are as a rule highly epidotized and have assumed a light-green color due to finely disseminated epidote. The minute needles of green hornblende which penetrate the rocks in all directions also combine to give a distinct green color to the igneous rocks.

The presence of magnetite within the quartz phenocrysts is another feature of some of these rocks which is thought to be due to the action of the solutions that brought in the ores. In the slides examined the development of magnetite in quartz was greatest in specimens taken near one of the larger hematite-magnetite veins. This fact, together with the observation that secondary green hornblende needles penetrate many of the quartz phenocrysts in all directions, leads to the belief that the magnetite within the quartz is secondary rather than original.

Surface weathering is comparatively slight in this desert region. In the ordinary exposure of compact rocks like the intrusive rocks now under discussion surface decay extends only to a small depth. Within this zone of decay the ferromagnesian minerals are completely altered to a yellow powdery material and the rock is usually soft and crumbly. Any metamorphic changes indicated below the zone of surface weathering must be attributed to the action of mineralizing solutions.

IRON ORES.

EXTENT AND STRUCTURE OF THE DEPOSITS.

The iron-ore veins composing the Iron Age deposit are fifty or more in number, of which less than ten are as much as 10 feet thick. There are four large veins, three of which are on the summit and south slope

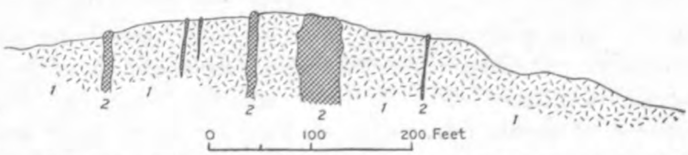


FIGURE 20.—Sketch showing structure of iron-ore veins of Iron Age deposit, near Dale, San Bernardino County, Cal. 1, Granite and granite porphyry; 2, iron ore.

of the hill and the fourth several hundred yards to the northwest. (See Pl. II.) The largest of these veins is about 425 feet long and varies from 15 to 100 feet in width. It is extremely irregular and has several large branches. The second largest vein is about 350 feet long and from 2 to 40 feet wide; the third in size is the longest vein in the area, being 500 feet long and from 2 to 25 feet wide. The vein northwest of the main hill is 375 feet long and from 2 to 15 feet wide. About 100 feet from the upper or east end of it, however, there is a short break. The smaller veins vary down to 5 or 10 feet in length and to 6 inches or less in thickness. But little development work has been done and the depth which the veins reach is unknown.

The veins occur both in the granite and in the granite porphyry. Their trend is predominantly north and south, though a few veins trend approximately east and west, and still fewer have intermediate directions. Most of them are nearly vertical, but some were noticed with dips as low as 60°. For the most part the veins are clean cut and have sharp contacts with the inclosing rocks. (See fig. 20.)

Along many of the veins there has been little or no impregnation of iron into the country rock, the latter being unaltered one-fourth of an inch from the contact except for the epidotization. Locally, however, the rock along the contact is brecciated for some distance, and elsewhere it is decomposed without much fracturing. Where brecciated it is in general strongly epidotized and impregnated with garnet and contains a network of small veins of magnetite, hematite, epidote, and garnet, with which are associated locally quartz, chalcedony, and calcite. The rock is brecciated at several places away from iron-ore veins, and at these places there is a similar impregnation and veining of iron and metamorphic minerals.

Adjacent to some of the veins the rock is kaolinized and stained brown by iron oxides for several feet from the vein contact. Small stringers of hematite, magnetite, or limonite traverse this decomposed zone and near them the rock is partly replaced by iron oxides. At many places the rock in contact with the main vein is altered for several inches to a yellowish or white kaolin-like material, soft and fissured. In a few places masses of much altered rock, some of them several feet in diameter, partly replaced by iron oxides, occur within solid iron-ore masses near their borders, showing that at least locally replacement has accompanied the vein filling during the ore formation. Such occurrences are related to the breccia deposits.

Near other veins where the rock is apparently unaltered except for the epidotization there is for 5 or 6 feet from the contact an abundant development of small iron-ore veins varying from mere seams to those half an inch in thickness, which appear to have produced little or no alteration in the adjacent rock. At one or two places it was noticed that the rock near the ore veins was aphanitic, but that from 3 to 5 feet from the contact large porphyritic crystals appeared, the groundmass remaining the same. Such changes in texture, however, are common throughout the area and probably are not the result of the ore formation, the occurrence near an iron-ore vein being merely a coincidence.

NATURE OF THE ORE.

The ore composing the veins is largely hematite, hard, reddish black, and crystalline. Magnetite is intermixed with it in many of the veins and is more abundant than hematite in a few veins. Limonite and goethite occur locally in negligible quantities along cracks and on surface exposures as shiny black, globular incrustations with needle-like texture. Limonite is found also in the yellow, porous, ocherous form. The hematite is by far the most important constituent, probably composing more than 90 per cent of the ore. The larger part of it is martite, pseudomorphic after magnetite, from which it was formed by oxidation. It varies in texture from very coarsely crystalline to finely crystalline and even granular. Some veins are so coarsely crystalline that partings parallel to the octahedral faces several inches in diameter are common. The coarsely crystalline hematite (martite) is comparatively free from magnetite, but all of the more finely crystalline ore carries disseminated magnetite. The magnetite also is in places coarsely crystalline, occurring in large octahedrons or dodecahedrons.

Quartz crystals are found in many of the veins, being generally stained red or brown in the hematite veins and white or colorless in the magnetitic parts. They have good crystal outlines, being usually isolated from each other. Quartz also occurs in the limonite and goethite incrustations. Calcite is found sparingly in small rhombic crystals associated with porous limonite and in fissures in the ore veins and breccias. Garnet and epidote do not occur with the ore in the veins but only in the breccias.

MINERALS ASSOCIATED WITH THE ORE.

The principal vein and metamorphic minerals developed in the intrusive rocks were probably formed in connection with the iron-ore deposits. They are largely epidote, garnet, and chalcedony, with a little vein quartz and calcite. Epidote is everywhere disseminated through the country rock. It occurs either as minute grains within the feldspars or as large irregular masses lying in any position in the rock or in fissures of varying width. In either situation it has evidently been formed through the alteration of feldspar by deep-seated solutions which brought in the lime and iron necessary for its formation.

Garnet occurs in veins with epidote and locally with epidote and calcite. Vein quartz and calcite cut the ore veins and rock here and there. Apatite occurs in some of the ore veins.

Small veins of magnetite or hematite traversing feldspar crystals show in many places definite crystal boundaries projecting into the feldspar. In several thin sections, especially those taken from the vicinity of large fissure veins of hematite or hematite and magnetite, many small crystals of magnetite may be seen developed within the quartz phenocrysts of the country rock.

As has already been stated, the general metamorphism to which the rocks of this area have been subjected and which probably accompanied the introduction of the iron ores has changed augite to green hornblende or to hornblende and chlorite, and has no doubt likewise brought about the extensive epidotization of the rocks.

The epidote in veins and breccias, as well as the fragments within the feldspars, is probably an alteration product from feldspar and was deposited in these places because of the mingling of solutions carrying feldspar decomposition materials with other solutions coming directly from a great depth. The epidote and garnet were apparently deposited at nearly the same time, the latter generally occurring in disseminated grains and bunches in the former. Locally, however, veins of garnet cut masses of epidote, showing that in such places the garnet came in later. The iron minerals were deposited still later in openings left by the garnet and epidote or in veins cutting them. In some of the brecciated areas epidote and garnet are rare and iron minerals alone form the cement by which the rock fragments are bound together. Chalcedony, quartz, and calcite are of later origin than the ore minerals, for they line cavities left by the preceding minerals and fill fissures that cut them.

The rock fragments composing the breccias and the more solid rock surrounding them are generally much altered and impregnated with secondary silicates and iron minerals. On the other hand, the rock near clean-cut iron-ore veins is as a rule but little altered.

Epidote and garnet are rare or absent in the clean-cut iron-ore veins, but quartz occurs abundantly and calcite locally. Most of the quartz is in crystals surrounded by hematite or magnetite, and was undoubtedly formed during the deposition of the iron ores. A part of the calcite is associated with garnet and epidote and is probably of the same origin as these minerals, but much of it is of later origin, occurring in fissures with limonite, with which some quartz also is associated.

Epidote and garnet, associated with quartz and calcite, occur at several places on the hill at some distance from iron ore, being found as small bunches surrounded by country rock, in small veins cutting the country rock, or as impregnations within the rock itself. Thus the iron minerals and the epidote and garnet, while undoubtedly related, occur at many places separately.

Surface deposits consisting of small angular fragments of iron ore intermixed with a few rock fragments and embedded in a compact cream-colored matrix of mixed calcareous and siliceous material occur at several places on the iron-ore hill, especially near the larger veins. Some of them are several feet in thickness and cover considerable areas, overlying either ore veins or country rock. Others fill open fissures in iron-ore veins. Fragments in these deposits may be several feet in diameter and such fragments may contain open fissures that are filled with the same cementing material. At a few points the deposits contain only rock fragments, iron-ore fragments being absent.

ORIGIN OF THE ORE.

The iron-ore veins composing the Iron Age deposit undoubtedly originated from hot, deep-seated solutions, being formed after the cooling and consolidation of the igneous rocks in which they occur. The principal facts pointing toward a deep-seated source for the ore-bearing solutions are the association of the hematite and magnetite with epidote and garnet, which are so characteristic of metasomatic replacement by deep-seated solutions, and the extensive epidotization of the rocks throughout the iron-ore area.

It is not possible to say definitely what was the nature of these solutions nor in what form the iron was carried. It is probable, however, that the solutions were hot, perhaps gaseous, because many of the veins are coarsely crystalline and in most of them the iron was originally deposited as magnetite. They carried lime as well as iron in solution, as is shown by the alteration of the soda feldspars to the lime-iron silicate epidote. The solutions came up from below through fissures and faults formed after the cooling and consolidation of the rocks. In many localities the wall rock was replaced by iron oxides to a considerable extent; elsewhere it was simply altered and decomposed by the solutions. Locally brecciated masses were encountered, and there, as well as in the larger fissures, the solutions spread out and deposited their material.

The formation of the epidote and garnet appears to have slightly preceded the deposition of the iron ore, or at least to have begun somewhat earlier. Quartz was deposited at intervals during the formation of the iron ore, and calcite in small amounts was deposited with garnet and epidote. The coatings of goethite and limonite with associated quartz and calcite are of later origin, being probably formed by deposition from meteoric waters.

The history of the intrusion and ore deposition may be summarized as follows:

(1) Intrusion of the granite porphyry into an unknown formation, followed closely by the intrusion of the soda granite, probably before the complete consolidation of the granite porphyry.

(2) Fracturing of the intrusive rocks after consolidation.

(3) Permeation of the igneous rocks by deep-seated mineralizing solutions, either liquid or gaseous, coming up through the fractures and probably containing as chief constituents iron and lime.

(4) Formation of epidote and garnet from materials derived from the partial alteration of the feldspars by the solutions, with the addition of lime and iron from the solutions, accompanied by the formation of small amounts of quartz and calcite. The epidotization took place throughout the rocks, but was most pronounced in brecciated zones. The solutions apparently carried but little silica, for the silica necessary for the formation of the silicates may easily have been derived from the altered rocks.

(5) Deposition of magnetite along fractures and in brecciated zones, associated with and followed by the deposition of small amounts of chalcedony and quartz.

(6) Alteration of magnetite to hematite by oxidation, followed by the local deposition of hydrous iron oxides, quartz, and calcite.

IRON ORES NEAR DAYTON, NEVADA.

By E. C. Harder.

LOCATION.

Dayton is a small village in eastern Lyon County, Nev., on the Carson and Colorado branch of the Southern Pacific Railroad. (See fig. 21.) It is best reached by the Virginia and Truckee Railway from Reno by way of Carson and Mound House. The village is on Carson River at the upper (southwest) end of a broad, flat desert, just below the point where the river runs out of the canyon below and east of Carson.

Two groups of iron-ore deposits are found near Dayton—a small one about 2 miles to the southwest, between the railroad and the river, and a large one about 12 miles to the northeast, on the boundary of Lyon and Storey counties. Only the latter is of commercial importance in the steel industry, but the ore from the former might be used in a small way as fluxing material.

DEPOSITS NORTHEAST OF DAYTON.

General distribution.—The iron ores northeast of Dayton are in an area of gently rolling hills which form the northeastern continuation of the flat desert area below Dayton. Northeast of the deposits there is another desert area with alkali flats, and beyond are other rolling hills. This generally low belt bounded on the northwest and southeast by mountain ranges is known as the Fortymile Desert. In the mountains to the northeast is the famous old Comstock lode, with Virginia City and Gold Hill high up on the slope.

The iron-ore deposits are near the northwest border of the desert belt. Outcrops of ore are distributed over an area roughly one-fourth of a mile wide and half a mile long (see fig. 22), the longer diameter being approximately north and south. At the south end of the area there is a hill rising about 75 or 100 feet above the surrounding area. Its crest is about 900 feet long and 200 feet wide and trends about N. 45° W. Iron-ore outcrops form the crest and extend some distance down the slopes. The northeast slope and the southeast slope below the iron-ore outcrops consist of a soda granite; the southwest slope is covered with rock débris. Below the iron ore on the northwest slope there is soda granite and crystalline limestone. South of the hill is a large area of horizontal conglomeratic limestone, probably a calcareous tufa, which in most of the area overlies soda granite. North of the hill is a broad, gently undulating flat extending for a mile or more, covered with float but showing a few ore and rock

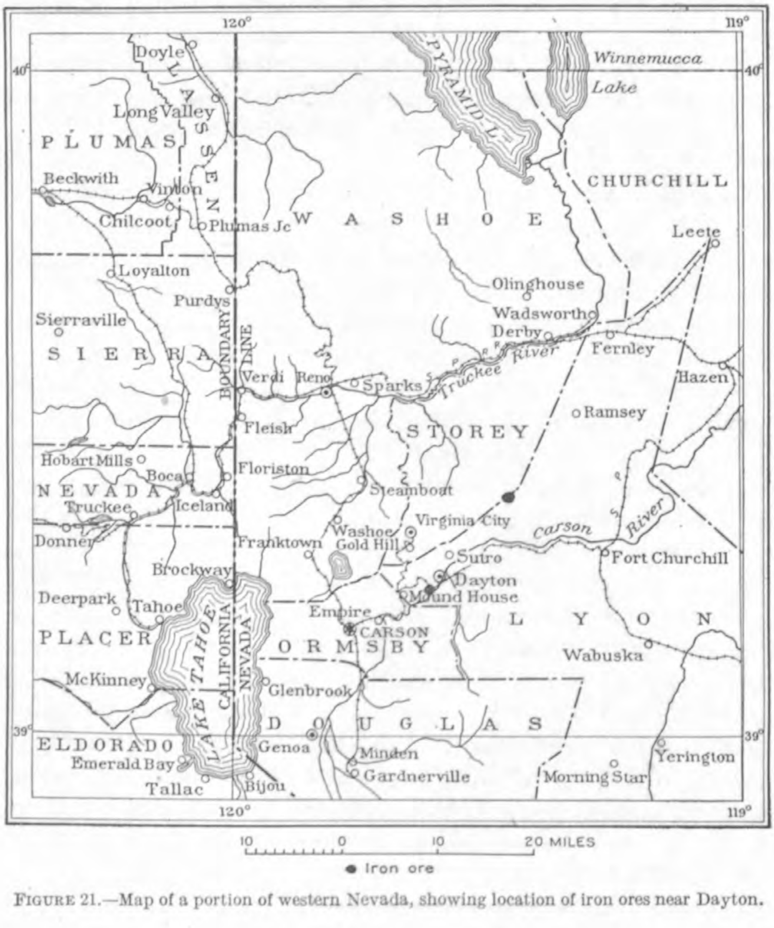


FIGURE 21.—Map of a portion of western Nevada, showing location of iron ores near Dayton.

outcrops here and there. The principal ore outcrops in this flat are about half a mile northeast of the ore hill. They consist of three masses arranged along a line about N. 60° W., and near them occur several outcrops of limestone and pits in soda granite. About 150 yards northwest of these outcrops, just west of a road that comes through the area from Dayton, there is a small knoll on which iron ore and soda granite outcrop. Two other ore outcrops lie close together about two-thirds of the distance from the three ore outcrops at the north end of the area to the main ore hill. A short distance southeast of these there is a low ridge on which granite and shale outcrop. No other outcrops occur within the iron-ore area.

A number of pits have been sunk on the flat north of the ore hill, but only three of them have struck bed rock, the others being in

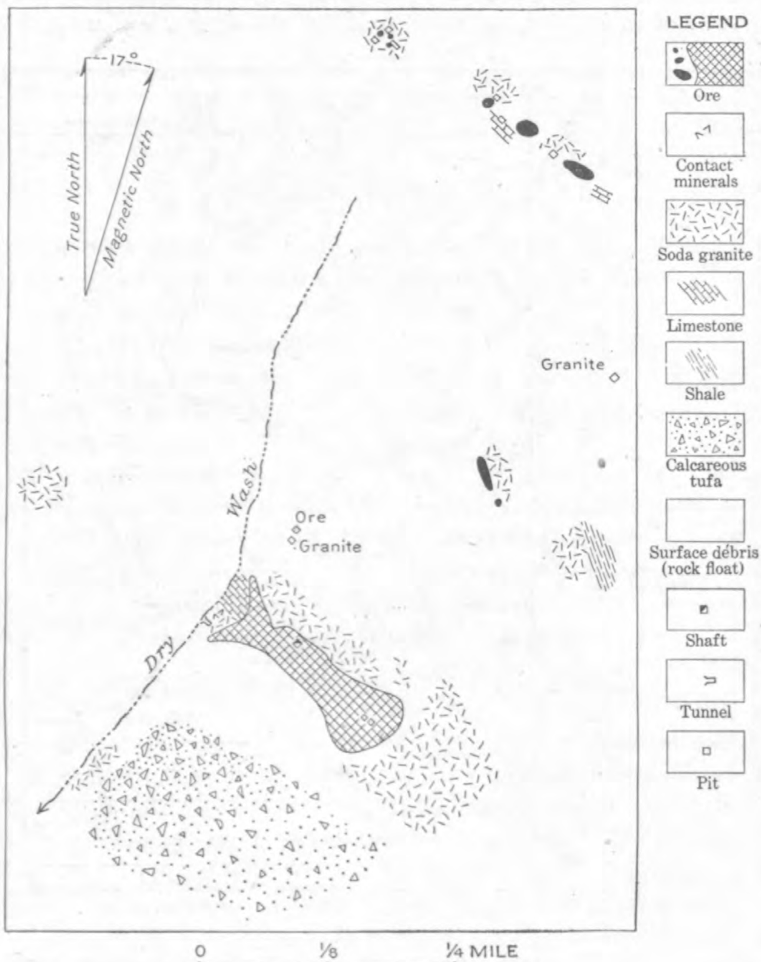


FIGURE 22.—Sketch of iron-ore area northeast of Dayton, Nev.

float to a depth of 10 or 20 feet. Of the pits which struck bed rock, one, a short distance southeast of the three ore outcrops at the north end of the area, reaches soda granite; of the other two, which are close together a short distance north of the ore hill, one reaches ore and the other soda granite. There are several tunnels and pits on the iron-ore hill.

From the distribution of ore and rock as shown by outcrops and pits it appears probable that the area is composed largely of soda granite, in part aplite, in which there are local masses of limestone and iron ore. Where the relation of the ore to the rocks is clear it is seen that the ore occurs at the contact of the limestone and granite. The soda granite has also broken into the limestone and ore masses in irregular intrusions. Metamorphic minerals, including garnet and epidote with a little albite, are developed locally.

Character of the rocks and ores.—The soda granite or aplite is a light-colored, medium-grained rock varying slightly in appearance in different parts of the area, because of the varying amount of dark mineral present. It is composed largely of orthoclase and quartz, in which are embedded larger crystals of albite and albite-oligoclase. Minor quantities of green hornblende, biotite, epidote, and chlorite occur. Locally the ferromagnesian minerals are almost absent and the rock is yellowish white and aplitic. The chlorite is derived from the alteration of the biotite, which has locally almost entirely disappeared. The feldspars are much altered to epidote and kaolin. Apatite and magnetite are accessory minerals.

The limestone where fresh is thoroughly crystalline and blue or white in color. Near the ore and granite, however, it has suffered some decomposition and is stained yellow or brownish. No bedding is apparent.

The calcareous tufa has a pronounced bedded structure and lies nearly flat. Some of the beds consist of massive though porous limestone; others contain an abundance of rock fragments and sand grains in a calcareous matrix.

The ore is a mixture of hematite, magnetite, and limonite, the hematite being the most abundant in the surface outcrops, though both magnetite and limonite occur with it and locally the magnetite is more abundant than the hematite. The ore is dull, hard, and somewhat porous at the surface; with increasing depth it becomes soft and granular and contains an abundance of calcite and locally gypsum (selenite) along fissures. The soft ore is largely magnetite. Garnet, quartz, calcite, epidote, and albite are present at several places along the contacts of ore and granite or limestone and granite. Epidote occurs in veins and masses cutting garnet. Albite is found in the epidote in such positions as to indicate that the latter is an alteration product of it. Here and there in the garnet masses are small veins of unaltered albite.

Occurrence of the ores.—The outcrops of ore on the hill at the south end of the iron-ore area occupy a space about 1,000 feet long and from 200 to 500 feet wide. Within this area there are one or two tongues of granite and the float between the outcrops may cover limestone or other granite bodies. The surface ore on the crest is hard and massive, though slightly porous in places. One shaft and several pits have been sunk into it. The pits have not passed through the hard ore, but the shaft goes into a soft, bluish, granular mixture of magnetite and calcite at a depth of less than 20 feet. Much selenite occurs with this soft ore.

On the northwest slope of the hill erosion has been very rapid because of an arroyo at the base; hence much of the hard surface ore has been removed and a soft granular mixture of magnetite and calcite similar to that in the pit on the crest of the hill is exposed in places. Here, also, selenite is abundant in cavities and along fissures. Some porous, hard, low-grade ore, with considerable impurities consisting largely of unreplaced siliceous rock, outcrops on the lower slope, but most of the ore outcropping on the upper slope is hard and massive, though mixed irregularly with it is the blue granular ore already mentioned. A mass of yellowish, somewhat altered crystalline limestone occurs near the base of the slope southwest of the low-grade ore exposures, and southwest of the limestone lie soda granite and contact rock, the granite occurring between the contact rock and the ore of the upper slope.

The contact rock consists of a mixture of epidote, garnet, and albite. The garnet was formed first, and the epidote occurs in it in veins and irregular masses. The garnet is reddish brown in color and is probably andradite. The epidote contains remnants of albite, of which it is probably an alteration product. Some veins of little-altered albite occur.

The granite near the base of the hill contains an abundance of biotite and is greenish gray in color. At other localities on the hill it is usually grayish white and contains biotite sparingly. A long tunnel entirely in dark granite is just above the wash at the base of the hill.

The three ore outcrops near the north end of the iron-ore area lie in a line about N. 60° W. The northwesternmost one is about 50 feet in diameter. Just north of it is a shallow test pit in granite and yellowish crystalline limestone. In this pit schistose granite occurs next to the ore, then limestone, and north of this blocky granite. Fragments of contact rock consisting largely of epidote, quartz, and calcite was found near the pit and probably came out of it. About 120 feet to the southeast is the second ore outcrop, approximately 100 feet in diameter. Between the first and second outcrops is an exposure of fresh blue and white crystalline limestone with nearly vertical north-south banding. A test pit has been sunk into it. The second ore outcrop is surrounded by float. The third ore outcrop is about 150 feet southeast of the second and is about 130 feet long and 60 feet wide. Between it and the second outcrop is a pit in fissured, blocky granite, and southeast of it is a small exposure of blue crystalline limestone banded in a northwest-southeast direction. The ore in all three outcrops is largely hematite, hard and massive, and of high grade.

On the knoll near the road there are several pits in iron ore and granite covering an area about 75 feet in diameter. The ore and rock are irregularly distributed, and no definite relation is apparent between them.

Of the two ore outcrops in the flat the one to the north is the larger, being 15 to 30 feet wide and 130 feet long. It trends approximately N. 15° W. and dips steeply to the west. East of it is granite; to the west is float. This ore is of very poor quality, being intermixed with much country rock, unaltered or only partly replaced by iron. The granite is stained and impregnated with iron oxide. One trench cuts across the ore band and a pit has been sunk at the contact of ore and granite. The other ore outcrop is about 25 feet in diameter, has a pit in the center, and is surrounded by float.

Origin and economic importance of ores.—From their occurrence the ores northeast of Dayton appear to be contact deposits formed during or after the intrusion of the granite into the limestone. This view is strengthened by the presence of minerals characteristic of intrusive contacts. The ores are probably partial replacements of the limestone, some of the original limestone being still present as local masses in the vicinity of the ore or occurring in the recrystallized form of calcite within the ore. The surface ore has been enriched and concentrated by the removal of calcite and probably by the deposition of iron oxides. The selenite may be simply a deposit near the surface from gypsiferous solutions or it may have been derived from the oxidation of pyrite, though this mineral has not been found in the ores.

Most of the surface ore is of high grade. In depth it appears, whenever penetrated, to be strongly impregnated with calcite. Locally enough calcite is present to make the ore self-fluxing, and therefore in reality the presence of calcite does not materially affect the value of the ore. The selenite may be abundant enough in places to necessitate dressing of the ore to reduce the sulphur content. If the ores were smelted in the electric furnace, however, the presence of selenite would not be objectionable. The depth to which the ores may extend is problematic, though the increasing amount of calcite with increasing depth suggests that the ore may become of too low grade to be worked. But the deposits are of sufficient size to be commercially important even if the ore is supposed to be relatively shallow. With a depth of 50 feet the deposit on the hill at the south end of the area would probably yield approximately 1,500,000 tons of ore. The deposits are on low ground and can easily be approached by a railroad either from Dayton or from the Nevada and California branch of the Southern Pacific Railroad to the east.

DEPOSITS SOUTHWEST OF DAYTON.

Veins of iron ore occur in a dark-green fine-grained andesite on the east slope of a ridge about 2 miles southwest of Dayton. They are seven or eight in number, and all except one are in a group, the exception lying several hundred yards to the north. The veins consist of a mixture of hematite and magnetite and vary from 25 to 100 feet in length and from 1 to 10 feet in width. In a few of the larger veins there are small lenses of schistose andesite, and along the walls of some of the veins the andesite is locally much fractured. Small ore veins occur as networks in the brecciated andesite. Apatite is an abundant constituent of some of the veins, crystals of it occurring transverse to the direction of the vein. Calcite occurs near the center of some of the veins and fills cavities in them.

THE JAUSS IRON MINE, DILLSBURG, PENNSYLVANIA.

By Arthur C. Spencer.

The iron-ore fields near Dillsburg, York County, Pa., were described by the writer in 1908,[a] the description being based on a careful study of the surface geology and such observations on the mines as had been recorded by other geologists, as no mining operations were in progress during the summers of 1906 and 1907. In April, 1910, the Jauss mine had been unwatered and was visited by the writer in company with Messrs. John N. Logan and John Morris, of Dillsburg, and E. C. Harder, of the Geological Survey.

The Jauss vertical shaft is situated near the east bank of Stoney Run (or Fishers Run), about 1½ miles east of Dillsburg, at the terminus of the branch railroad. The following notes are quoted from Bulletin 359:

> The shaft was sunk at a point where the dip needle showed a marked magnetic attraction. About 72 feet of diabase was penetrated before the 7-foot ore bed was encountered. The floor of the mine is limestone conglomerate. As depth was gained the ore bed was found to thicken along the dip, and in the lowest workings, 205 feet below the surface, a large body of ore is reported. Stoping was carried about 30 feet above the point where the ore was cut through by the shaft. A survey made in 1888 shows the mine workings as extending 270 feet northwest of the shaft. In this distance the ore bed falls 133 feet, giving an average inclination of nearly 50 feet per 100, or about 30°. The dip appears to be somewhat steeper in the lower than in the upper workings.
>
> Material on the waste pile shows that some of the ore at least has been formed by replacement of limestone conglomerate, though most of the material intimately associated with the ore appears to be an altered shale. Although no fragments of any rock except diabase are to be seen in the field south of the shaft, there can be little doubt that the sedimentary rocks which accompany the ore would be found beneath a relatively shallow cover of soil.

It is now apparent that several statements in the foregoing quotation are incorrect, and the following description may be substituted:

The shaft was located by Mr. Logan because of a marked magnetic attraction. After about 72 feet of diabase had been penetrated ore

[a] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: Bull. U. S. Geol. Survey No. 359, 1908, pp. 71-96.

was encountered and found to be about 7 feet thick. On the south side of the shaft the diabase is seen to be very close grained and dense, and the contact dips in a southerly direction, which makes it appear that the intrusive rock is here cutting across the edges of the stratified rocks, which dip north-northeast. There is no indication that the ore continues toward the surface, so that the supposed sedimentary outcrop south of the shaft probably does not exist. The shaft seems to have encountered the crest of the ore body. In the western part of the workings diabase was noted in the highest stope. Here it apparently forms the roof over the north-northeastward-dipping ore.

Mr. Morris, who has been in touch with most of the mining operations in the Dillsburg field, believes that the upper ore layer in the Jauss mine lies very close to the bottom of the diabase. This view the writer is inclined to accept, but actual observations are lacking to settle the matter definitely, no diabase being visible in the mine at points other than the two already mentioned.

From the bottom of the shaft the ore was followed by a zigzag incline from which stopes were extended to the right and left. The general course of the incline is about N. 30° W., and its slope, varying from place to place, averages about 17°.

In general the dip of the ore layers seems to be steeper than the slope of the incline, so that the line of the track lies between the direction of average strike and the direction of dip. In the bottom of the mine the dip is 12° NNE.

About halfway down the slope the roof of the ore was broken through and a second ore layer discovered. The parting is a light pink dense rock, thought to be baked shale. In the lower part of the mine considerable good ore was mined from this upper layer. Here the workings have exposed the upper ore bed 5 feet, parting 3 feet, and main ore 7 to 8 feet. A drill hole in the floor is reported to have revealed a third ore layer 7 feet thick. The thickness of the parting between the lower and the main ore bed was not learned.

Examination of the stopes shows that the ore layers are lenticular in cross section, and it is presumed that the incline follows the thickest part of the main ore layer. Mr. Morris states that thinning of the ore bodies on both sides of an axial line is a marked characteristic of the Dillsburg field, being noted by him in the Bell, the King (or McClure), and the Longnecker.

Examination of the Jauss mine workings makes it very clear that the ore has been formed by the replacement of layers of stratified rocks and that the process of replacement was controlled by differences of composition in the strata involved. In the stopes the ore faces exhibit a characteristically mottled effect, which is the result of incomplete replacement of the rock constituting the ore layers. It appears that these layers were originally beds of limestone conglomerate and that the barren partings between the ore layers were beds of shale. During the period of ore formation iron-bearing solutions transfused through these rocks and replaced their constituents more or less completely in different situations. The mottled ore seems to represent what was originally limestone conglomerate in which the pebbles have been replaced by magnetite and associated pyrite more completely than the cement or matrix. In places where the ore is more massive than usual the whole rock (pebbles and matrix together) has been converted into ore. Unmetamorphosed conglomerate has not been encountered in the mine.

The proved existence of three layers of ore in the lower part of the mine leads to the suggestion that there may be at least one more vein beneath the ore encountered just under the diabase at the shaft. It would seem to be worth while to drill through the floor of the mine in several places and to carry test holes down as far as the rocks show evidence of having been metamorphosed. The presence of crystalline limestone or of fragments of chlorite (flexible green mica), garnet, or epidote in the drill cuttings may be safely taken as evidence of metamorphic alteration.

The limestone conglomerate beds of the Dillsburg field lie near the bottom of the Triassic rocks, and it is believed that blue Paleozoic limestone (like that which is quarried near Dillsburg Junction) exists at moderate depth beneath the Jauss ore. The distance to the underlying blue limestone may be less than 50 feet and can hardly be more than 100 feet, measured across the stratification.

It may be suggested that a favorable situation for ore deposition would be adjacent to the surface between the blue limestone and the Triassic strata. Such indeed is the position of the ore layers at Grantham station, 4 miles north of the Jauss mine, where along the railroad track the limestone conglomerate is found at the base of the Triassic overlap on the blue limestone.

DEPOSITS OF BROWN IRON ORE NEAR DILLSBURG, YORK COUNTY, PENNSYLVANIA.

By E. C. Harder.

GENERAL STATEMENT.

Dillsburg, Pa., is a small village on the Cumberland Valley Railroad, about 15 miles southwest of Harrisburg. It is situated just within the border of the Mesozoic belt southeast of South Mountain, which here consists largely of Cambrian sandstone and quartzite. Northwest of the mountain is the Appalachian Valley, underlain by Cambrian limestone, shale, and sandstone.

The Mesozoic belt, trending northeast and southwest, has a width of about 18 miles at this point, extending southeastward from Dillsburg almost to York. The rocks composing it are red sandstones and shales intruded by large masses of diabase. Near the intrusions the sandstones are baked and discolored. The red sandstones lie on a basement of Paleozoic or older rocks. Wherever they lie on limestone the basal part of the series contains numerous layers of limestone conglomerate. Within the general sandstone series are interbedded calcareous layers.

The iron ores of the Dillsburg district are of two types—magnetite deposits scattered through an area about a mile square, the center of which is about 1½ miles east of Dillsburg, and brown-ore deposits on the slope of South Mountain north of Dogwood Run, from 2 to 3 miles west of Dillsburg. The magnetite deposits are in Mesozoic sediments near the contact with intrusive diabase; the brown ores occur in variegated clays associated with Lower Cambrian (Antietam) sandstone.

The geology and magnetite deposits of the Dillsburg district are described in detail in a former report of the Survey.[a]

BROWN-ORE MINES.

LOCATION AND HISTORY.

The brown-ore mines near Dillsburg are situated in an area about a mile in length in a northeast-southwest direction and several hundred

[a] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: Bull. U. S. Geol. Survey No. 359, 1908, pp. 71-100.

yards in width, the easternmost mine in the belt, the Pinkerton bank, being about 2 miles west of Dillsburg. The area is near the foot of the southeast slope of the northern ridge of South Mountain northwest of Dogwood Run, which drains northeastward from the mountain into the Mesozoic area. This ridge rises about 800 feet above the floor of the valley of Dogwood Run. Southeast of the valley is another ridge which rises to about the same height. The general trend of South Mountain is northeast-southwest. Five or six mines were operated along this belt in former years, but eventually one after another stopped operating, and for many years no ore was produced. The old pits and underground workings fell in and were overgrown by underbrush and trees. The large open cuts, slush dams, and waste dumps, however, still bear evidence of former extensive operations.

The principal old mines along the belt were, from east to west, the Dogwood (McCormick), Knaub, Heck, Brant & Arnold (Lexier), and Markley & Shank (Old Wolf).[a] Of these the McCormick, with a formerly unworked area east of it, is now included in the Pinkerton tract; the rest are on the Marshall tract.

Recently mining operations have been recommenced on both of these tracts. On the Pinkerton tract an extensive open cut several hundred yards long and up to a hundred feet in width has been made along the slope of the mountain northeastward from the old McCormick workings. This has been simply a stripping operation, the barren surface clay and rock débris being removed and the underlying ore-bearing clay exposed and penetrated for a short distance. No ore has been produced and work has been temporarily suspended.

On the Marshall tract the old Heck mine is being operated. This mine consisted of an open cut several hundred yards long extending along the slope of the mountain and a long tunnel which tapped the ore body below the cut. A deep pit has been sunk in the bottom of the old cut at its southwest end and the ore is mined by the milling method, being delivered from the walls of the pit into the tunnel below it and hauled in cars to the washer. An incline has been sunk near the washer, which taps the ore body some distance below the tunnel level and here ore is mined by underground methods.

GEOLOGY.

South Mountain extends northeastward from Franklin County along the boundary of Cumberland and Adams counties and ends on the northwest border of York County. It terminates abruptly northwest of Dillsburg, dropping off on the north into the gently undulating valley region and on the east and south into the rougher

[a] D'Invilliers, E. A., Report on the iron-ore mines and limestone quarries of the Cumberland-Lebanon Valley, 1886: Ann. Rept. Pennsylvania Geol. Survey, 1886, pt. 4, pp. 1473-1480.

Mesozoic region, which consists of hills and ridges of trap, with intervening valleys, largely underlain by sediments.

The northeast end of South Mountain consists structurally of two parallel anticlines of northeast-southwest trend forming the two prominent ridges between which lies the synclinal valley of Dogwood Run. The summits of the ridges are composed of the Montalto quartzite; the lower slopes consist of Antietam sandstone. The valley of Dogwood Run is thought to be underlain by the Tomstown limestone, this being the normal Lower Cambrian succession.[a] No outcrops of it occur, however. About 25 miles to the southwest, in Franklin County, the Montalto quartzite becomes simply a member of the Harpers schist. The dip of the rocks on the slope north of Dogwood Run is at a steep angle to the south.

The Antietam sandstone is covered by a blanket of mountain débris of varying thickness, consisting of sand and brown sandy clay, in which are embedded angular fragments of the mountain sandstone. South of the Antietam sandstone are variegated clays which are in part residual from it but are probably in the main residual from the Tomstown limestone. The contact between the variegated residual clays and the Antietam sandstone is very irregular and numerous horses of sandstone occur in the clays near the contact. In these clays, along the nearly vertical contact with the Antietam sandstone, are the iron ores. The variegated clays reach a considerable depth, ranging perhaps up to several hundred feet vertically, and are presumably underlain by the Tomstown limestone. They are overlain by a blanket of mountain débris similar to that which overlies the sandstone on the slope above and which continues down to the valley. Little or no iron ore occurs in this blanket. It ranges in thickness from 5 to 30 feet and dips southward with the slope of the mountain. Its contact with the variegated clays is fairly regular.

The Antietam sandstone is generally white, grayish, yellowish, or reddish and coarse grained and does not appear to be quartzitic. The variegated clays are extremely varied in color and texture. They range from powdery yellow or brown ocherous material to dense, fine-textured clay of various colors, such as white, pink, purple, and red. Iron ores occur in all of them, but are most abundant in the yellow and brown ocherous clays, the color of which is due largely to the iron oxide they contain. The iron ores occur in seams, pockets, and irregular porous masses in the clay, without apparent definite relations to one another or to the inclosing clay. There is, however, a definite ore-bearing zone extending continuously along the slope of the mountain throughout the area, and along this zone all the principal deposits are found.

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[a] Stose, G. W., unpublished notes.

ORE DEPOSITS.

The principal ore deposits occur in a vertical or steeply southeastward-dipping zone up to a hundred feet or more in width, extending northeast and southwest for perhaps over a mile. The outcrop of the zone is on the lower slope of the mountain, ranging from 50 to 150 feet in elevation above the valley bottom. A narrower zone occurs locally south of the main zone, being separated from it by a considerable thickness of barren clay. At the Heck mine the principal ore zone has a thickness of about 65 feet. The minor ore zone is said to be about 5 feet thick and is separated from the principal zone by about 50 feet of barren clay. It is not mined at the Heck mine. North of the principal ore layer at the Heck mine there is barren clay in the upper part of the pit, and beyond this, probably but a short distance, is the Antietam sandstone. In the lower part of the pit the sandstone occurs as horses in the ore-bearing clay near the north wall. The depth to which the principal ore zone reaches is not known, but it has been operated to a depth of about 125 or 150 feet from the surface. All the old mines, as well as the Pinkerton and Heck, are apparently situated along this ore belt.

The ore is brown ore intermediate between limonite and goethite. It occurs in large irregular masses, in seams, and in small pockets scattered through the clay. Locally pockets and seams are arranged along horizontal planes, but in most places their distribution is irregular. Single seams may vary down to a fraction of an inch in thickness and single pockets to a foot or less.

The texture of the ore varies greatly. Some parts of a mass may be compact, others porous and cellular. Some of the ore is massive and granular in texture, some is shaly, and some ocherous. Ocherous material usually occurs in cavities in the cellular ore. Much of the ore that occurs as seams is shaly, and the ore in compact masses is granular.

The proportion of ore to clay varies greatly, but in the ore mined at the Heck mine the proportion by bulk at present is about 1 to $2\frac{1}{2}$. Twelve mine cars (capacity $1\frac{1}{4}$ cubic yards) yield after washing and concentration one dinky car (capacity $4\frac{1}{2}$ cubic yards) of shipping ore. The average metallic-iron content of the shipping ore is 45 per cent.

MINING METHODS.

The methods of mining and concentrating employed at the Heck mine are typical of brown-ore mining operations elsewhere in the Appalachian region. The ore is removed from the walls of the pit by a combination of blasting and pick and shovel operations. It slides to the bottom of the pit, where it runs through chutes into cars in the tunnel and is hauled to the washer located near the bottom of the valley. In the incline the ore is mined by drifting and stoping and is raised in cars up the incline to the washer.

In the washer the ore is first crushed to a convenient size and then washed in log washers to remove the clay and screened so as to separate the coarse from the fine material. Both grades are concentrated by jigging, to separate the ore from rock fragments. Only the fragments lighter than the ore can be removed, and frequently there is considerable sandstone mixed with the ore, thus lowering the grade. In general, however, the shipping ore from the Heck mine is of better grade than that of most mountain brown-ore mines using similar methods of concentration.

ORIGIN OF THE ORES.

The brown ores near Dillsburg belong to the type known as "mountain" ores, which are common in the eastern part of the Appalachian Valley throughout its extent from Vermont to Alabama. They are clearly the product of concentration by meteoric waters. The iron was derived from iron minerals disseminated through beds which originally overlay the places now occupied by the ore bodies. These strata were shale, sandstone, and limestone. In the shale the iron was probably present largely in the ferrous silicates and as pyrite; in the sandstone it probably occurred largely as pyrite, and in the limestone as pyrite and iron carbonate. Although most of the ore was probably derived from sediments stratigraphically overlying the Antietam sandstone, with which the deposits are now associated, part of it was doubtless derived from portions of the Antietam that are at a higher elevation than the present ore deposits.

Solutions percolating downward through the sediments decomposed the iron minerals, carried the iron downward, and redeposited it where conditions were favorable. Several conditions may have favored the deposition of the ores in their present position. The Antietam sandstone may have obstructed the further downward percolation of the iron-bearing solutions, which consequently deposited much of their material along its upper contact. It is also possible that the present ore zone is on a line of faulting along which there has occurred a mingling of iron-bearing solutions with oxidizing solutions, causing the deposition of the iron as hydrous ferric oxide. Structurally, however, there is no evidence for such a fault, and the regularity with which the mountain ores throughout the Appalachian belt are associated with one particular sandstone formation beneath a great thickness of shale and limestone leads to the belief that a more general explanation is necessary. Such an explanation is offered by the hypothesis that the sandstone has acted as an impervious basement. Nevertheless, faulting may have been an important factor.

The iron was deposited immediately in its present form—that is, as hydrous ferric oxide in pockets and irregular masses in clay. Some of the ore masses were deposited in open spaces; others are largely replacements of clay. The ore bodies are now in the places in which they were originally laid down, or nearly so, and are not mechanical concentrations of masses of ore originally deposited elsewhere, as is held by some investigators.

The localization of the ore bodies is controlled by the structure and by the distribution in the sediments of the original iron minerals from which the ore bodies were formed. The largest deposits probably occur where the overlying sediments were richest in iron minerals or perhaps contained large bodies of pyrite. Faulting and other structural features, however, may also have had considerable influence on the localization.

PRELIMINARY REPORT ON PRE-CAMBRIAN GEOLOGY AND IRON ORES OF LLANO COUNTY, TEXAS.

By Sidney Paige.

INTRODUCTION.

The present report is a brief statement of the pre-Cambrian geologic relations in Llano and Burnet counties, Tex., with a summary of the important facts concerning the Llano County iron ores. A bulletin to appear later will describe the geology and iron-ore deposits in detail, with geologic maps, sections of mines, and other illustrations, and will include an account of the graphite, gold, and other minerals present in the region.

The writer wishes to acknowledge his association in the field and office with Dr. A. C. Spencer, whose experience in the study of pre-Cambrian geology and iron ores has been of great value. The work was assigned to the writer on Doctor Spencer's departure for another field.

GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS.

Llano and Burnet counties are located in central Texas. The region is accessible by the Houston and Texas Central Railroad, which terminates at Llano, the county seat of Llano County.

The region occupies a peculiar position in the broad geologic province of which Texas is a part. Located about midway between the western Cordillera and the Gulf of Mexico, it forms a portion of a broad regional coastward slope, with the peculiarity that erosion has revealed rocks of the oldest known periods in a suboval area largely included within the Llano and Burnet quadrangles, as mapped by the Geological Survey. This area is nearly surrounded by Cretaceous rocks on its outer border, but rocks of pre-Cambrian and Paleozoic age are revealed within it and about its edge. The most casual observer will be impressed with the basin-like form of the broad valley of Llano River. Standing upon an eminence such as Town Peak, near Llano, he can see a broad rolling plain stretching east, west, north, and south, interrupted only by isolated hills as far as the horizon line, which is marked by the encircling scarp of Paleozoic rocks. In traversing this broad stretch of territory one finds many minor irregularities. The basin is a structural and erosional feature, the physiographic signification of which will not be discussed here.

GEOLOGY.

The rocks of the Llano-Burnet region fall naturally into three broad subdivisions—(1) pre-Cambrian schists, gneisses, and granites; (2) Paleozoic sandstones, limestones, and shales; and (3) Cretaceous sandstones, clays, and limestones.

The Paleozoic and Cretaceous strata completely surround the pre-Cambrian area; the Paleozoic beds are more or less folded and faulted and are separated from the pre-Cambrian by a great time interval. The Cretaceous formations rest upon the Paleozoic rocks in almost undisturbed position, but are separated from them by a great erosional unconformity.

PRE-CAMBRIAN ROCKS.

GENERAL DESCRIPTION OF GEOLOGIC UNITS.

Pre-Cambrian rocks underlie by far the larger part of the Llano quadrangle and about one-third of the Burnet quadrangle. In the mapping of the area four major divisions have been distinguished—(1) a schist series, predominantly of a basic type, including amphibolite, mica schists, and old basic intrusives; (2) a schist-gneiss series, including quartzites or their derivatives, light-colored mica schists and acidic gneisses; (3) a very coarse grained pink granite which could not be separated over the entire area; (4) all remaining granites, including a number of varieties. In addition to these major distinctions, wherever possible limestone and wollastonite bands have been mapped and the outcrops of a quartz porphyry of peculiar type, locally termed "opaline granite," have been indicated. The location of iron ore and other prospects is also shown.

GRANITES.

The granite is invariably intrusive. It cuts the schist series in large and small masses, in dikes, and in sills and, in pegmatitic phases, may be found both in minute veinlets and in huge dikes and sheets. It is almost an omnipresent rock. Every gradation may be found between pure granite and pure schist. Certain localities are characterized by pure granite masses of batholithic type, such as the area of coarse granite in the southwestern portion of the Llano quadrangle, the area immediately west of Cedar Mountain, and the area east of Lone Grove. Other areas are occupied by an intimate mixture of granite and schist, the schist being the sponge which apparently has literally soaked up and become permeated with granitic material. Such occurrences are best developed about the edges of the large granitic masses, though not at all confined to these bodies.

The manner in which intrusion was effected varied. Portions of the schists were in a plastic state and flowed under the influence of pressure. At other localities the contacts of cutting dikes are sharp, indicating a condition of considerable rigidity. At still others the temperatures were such that the schist masses lost their identity and passed by gradual melting into solution. Following the planes of least resistance, granitic material was often forced between the layers of the schists, forming injection gneisses.

Each of the processes outlined above has taken place both on a small and on a huge scale. The whole assemblage of rocks affords a fine example of the condition existing about the borders of a great batholithic mass in contact with a sedimentary series.

Worthy of special mention are the dikes, sills, and broader masses of pegmatite which occur in great abundance and in all sizes; the broader masses are of special interest, being locally developed at crosscutting contacts of schist with granite dikes.

Two types of granite have been distinguished and mapped—a very coarse grained rock and a medium to fine grained granite. Microscopic examination has shown that the distinction is a purely textural one, the mineralogy of the two being essentially the same.

The coarse-grained granite has been mapped in two areas, one in the southwest corner of the Llano quadrangle, forming a large subcircular area with Prairie Mountain as a center, the other to the north in the vicinity of Smoothingiron Mountain. Rock of the same type is known to occur to the east and southeast of Lone Grove and in other localities but could not be consistently differentiated in mapping.

The granite of the second type, the dominant rock of the region, is, as has been pointed out, very widespread. It comprises various textural types, from very coarse to very fine grained, but the whole has been mapped as a unit.

An examination of numerous specimens revealed an abundance of microcline, with orthoclase, albite-oligoclase, hornblende, quartz, and biotite. The granites are distinctly potash rocks, though soda is almost invariably present. The usual accessory minerals, magnetite, apatite, titanite, etc., may generally be found.

Several hornblende granites were noted, but their distribution is limited to small areas.

The "opaline granite," which is properly a quartz-feldspar porphyry, occurs as dikelike masses cutting both the schist series and the granites.

SCHISTS AND GNEISSES.

DISTRIBUTION.

Two broad divisions of the schist-gneiss series may be recognized and have been mapped. One is a group dominantly basic and generally of dark color, containing much limestone and graphitic material; the other a group dominantly acidic, of light color, and containing some altered limestone. Bands of acidic material are present in the first group and bands of basic dark material have been included in the second. There is, therefore, a transition zone between the two groups, locally offering difficulties to the placing of definite boundaries. Likewise at many places within the acidic group the distinction for purposes of mapping between invading granites and gneisses is exceedingly difficult.

The distribution of the two series is dependent primarily on their major structural relations, modified by the effects of igneous intrusion. Their general northwest-southeast trend is determined by the major axes of folding, and their lack of continuity along this trend is due to the presence of granite.

Two major anticlinal axes are present, one passing northwest and southeast through the center of the mountainous mass just west of Oxford, the other passing from Packsaddle Mountain northwestward to a point several miles west of Babyhead. Between these two anticlinal axes lies a major synclinal axis passing northwest and southeast a short distance west of Llano. The broad band determined by this synclinal axis is composed largely of the darker schists; the anticlinal axes mark areas of the lighter rocks. The basic schists overlie those of the acidic type, and therefore are found on the eroded flanks of these great folds where not disturbed by granite masses. The major axes of folding do not represent a simple structure. Minor folds are imposed upon the major folds, with the result that local complexities of structure are numerous.

THE DARK-COLORED SERIES.

The darker-colored series of rocks includes mica, amphibole, and graphitic schists and crystalline limestones. Within the series are also lighter-colored, more feldspathic bands, resembling quartzites. Basic intrusive rocks of earlier age than the granite are also present, locally in considerable amount. They have been mapped separately from the remainder of the series at one locality only.

As a whole, these schists are characterized by an excellent cleavage which for the most part accords in attitude with an original bedding in the sediments of which they represent the metamorphosed equivalents. Commonly, though not invariably, the graphitic schists are closely associated with limestones. The limestones are developed to a varying degree, separate bands aggregating 1,000 feet or more in thickness being found in some places. In general they occur most abundantly in the dark-colored series of rocks and are in a measure characteristic of that series, but they occur also in the lighter-colored rocks, though usually in a yet more altered form—that is, as wollastonite bands. The graphitic schists carry varying proportions of graphite—locally, it is believed, a sufficiently high content to be of commercial value. A discussion of this point will be reserved for a later report. The remaining types include amphibole, mica, tourmaline, and quartz-feldspar schists.

THE LIGHT-COLORED SERIES.

The mapping of the light-colored group of rocks was locally attended with much difficulty, partly in separating them from the dark series, but primarily because of their relation to granitic intrusions which, as has been pointed out, are widespread and of all degrees of magnitude. As many of the light schists closely resemble the granites, especially where slight schistosity may have been impressed upon the latter, and as the contacts are exceedingly irregular, a feature characteristic of the borders of large intrusive masses, the boundaries placed on the map must not be considered without exception as definite lines, but many of them rather as an expression of dominance of rock type. In a region where intrusive material has so completely interleaved and often fairly impregnated a rock mass, and where all gradations from the pure granite through phases of a mixture to pure schist exist, such boundaries as have been used are a necessity to express the geologic facts.[a] It is believed also that included with the schists and gneisses of sedimentary origin are old gneisses of igneous origin.

It has been noted that the areas of light schists include dark bands, though not abundantly, and also bands of wollastonite, the metamorphosed equivalent of limestone.

ORIGIN OF THE SCHISTS AND GNEISSES.

The rocks described above, in both the light and the dark series, are all completely crystallized—that is, the arrangement and size and in part the composition of their mineral constituents are due to the influence of heat and pressure and partly to flowage as a mass. The presence of crystalline limestones, of graphite, and of mica and amphibole schists that are traceable for long distances and retain the characteristics of beds leaves no room for doubt that in great part these rocks were formed by the metamorphism of a sedimentary series. It is believed also that the presence of iron ore points to the same conclusions, but this matter can not be fully considered here.

[a] In many places, however, the boundaries are fairly sharp and are definite lines. It is not possible to discriminate on the map between the boundaries of the two classes.

Although, as has been pointed out, the presence of old igneous masses of acidic type is suspected, only rarely was a crosscutting acidic dike found which bore evidence of having suffered equal metamorphism with the schists that it cut.

Intrusives of a basic type, gabbros and diorites, occur within the schist series and in part have suffered a like degree of metamorphism, though in part not. They will be described more fully in a later paper.

IRON ORES.

GENERAL DESCRIPTION.

Iron ores composed essentially of magnetic iron oxide, or magnetite (Fe_3O_4), or of admixtures of magnetite with hematite (Fe_2O_3) occur in deposits of noteworthy size in Llano and Mason counties, Tex. During the progress of geologic mapping of the Llano quadrangle in 1908 and 1909 thirty-two more or less distinct occurrences of such iron ore were noted and studied with as much detail as was warranted by generally poor natural exposures and a very meager amount of exploratory development. A few of these localities are in eastern Mason County, but most of them are in that portion of Llano County which lies north of Llano River.

All the known occurrences of magnetite were visited, but it is believed that perhaps not more than three of the deposits promise to become of industrial value. No assurance can be given that the three most likely deposits can be developed into profitable mines in advance of adequate exploration by means of diamond drills or by sinking prospecting shafts in addition to those already opened. It is considered that the less promising deposits will not warrant any large expenditure for prospecting unless the market value of iron ores increases.

The permissible scope of the geologic work did not admit of magnetic surveys, but it is strongly urged that such surveys should be carried on in connection with any future exploration of the more promising magnetic deposits of this district. Rough surveys with compass and dip needle are perhaps never fully adequate guides in the preliminary exploration of iron-ore deposits, and work with the more delicate instruments known as magnetometers is ordinarily to be recommended. Such instruments in the hands of skilled operators are certainly demanded by the conditions encountered in the central Texas region, where different parts of any individual ore body possess magnetic permeability in different degrees.

Those who may take up the problem of the practical development of the Llano County iron ores will doubtless give due consideration to the possibility of applying magnetic concentration, as processes of this sort are becoming more and more firmly established in various parts of the world.

The following descriptions are preliminary statements. The deposits will be discussed in more detail in a forthcoming bulletin of the Survey.

The deposits of magnetite in Llano and Mason counties, Tex., are typically layered or stratiform ore bodies conforming in attitude with the layering of the somewhat schistose rocks by which they are inclosed. The feature of layering is more marked in the leaner ore bodies than in the deposits of higher grade, but may be made out in nearly every locality where the iron-bearing rocks are adequately exposed for any sort of an examination. So far as could be observed the iron ores are an integral part of the schist-gneiss series and exhibit much the same relationships to the other members as the limestones and graphite schists. The ore-bearing rocks are crystalline granular schists in which the ore occurs as more or less concentrated grains of magnetite (or hematite when weathered). A single exception noted is the small ore mass opened by the Gallihaw shaft, which occurs in a dike cutting across the layering of the local gneiss.

In so far as the geologic mapping may be relied on, the deposits are associated mainly with the lower of the two sets of gneisses which have been broadly separated. The difficulties of consistently discriminating between these rocks have, however, proved to be so great that it must be freely admitted that the immediate country rocks of the ores may be representative of the upper set of schists in certain localities. If any mistake has been made in the proper classification of the country rocks it is in places where the upper schists have suffered excessive metamorphism and where they occupy areas of minor extent.

Two extensive occurrences of magnetite were found within areas which are undoubtedly underlain by the upper dark schists, and a small amount of magnetite was noted at one other place in this rock. The Olive ore deposit, one of these occurrences, is in dark schists near beds of limestone and very near the edge of a great intrusion of coarse granite.

DESCRIPTION OF LOCALITIES.

OLIVE PROPERTY.

The Olive iron-ore property is located on Little Llano River about 6 miles east by northeast of Llano, 1 mile south of Lone Grove post-office, and 1 mile north of Llano River and the line of the Houston and Texas Central Railroad.

The property has been more extensively developed than any other in the district. It was opened by a shaft in 1892 or 1893. The shaft is situated on the east bank of the Little Llano just west of the main boundary of this area and therefore within the schists which belong to the upper set of metamorphosed sedimentary rocks characteristic of the region.

The rocks exposed in the vicinity include granite, hornblende-mica schist, graphite schist, and crystalline limestone. The granites are intruded into the other rocks in an intricate manner, which can not be fully made out because of rather poor exposures.

The stock pile contains perhaps 400 tons of ore of very good physical appearance. Most of the ore contains hornblende, and some of it carries iron sulphide in addition to magnetite. It is all more or less distinctly layered in its make-up.

The following analyses are given by the courtesy of Messrs. Johnston, Elliot & Co., of Dallas, Tex. Both samples represent the stock pile at the Olive mine:

Analyses of ore from Olive mine, Llano County, Tex.[a]

Iron	57.80	Iron	54.35
Silica	8.40	Silica	10.16
Sulphur	.28	Sulphur	.55
Phosphorus	Trace.	Phosphorus	.021

The Olive ore was discovered at a point about 95 feet north by northeast of the working shaft. There is no surface showing and the ore is said to have been uncovered by accident in a shallow excavation. The first development was by means of an incline about 30 feet deep and a southerly drift which was afterward connected with the vertical working shaft. The shaft, which was started in the hanging wall, encountered the ore below the level of the drift mentioned above. It was carried down through the ore, and three crosscuts were run out to the ore. The shaft is 230 feet deep.

The following note by J. B. Dabney, former superintendent of the Olive mine, is furnished by Prof. N. J. Badu, of Llano:

* * * thickness of vein above first level, 3 feet; between first and second levels, 6 feet; between third and fourth levels, 8 feet; at fourth level, 2 feet; and at bottom of incline, 8 feet.

The horizontal extent of the ore has not been adequately tested.

BADER TRACT.

The property known as the Bader tract lies about 9 miles west of Llano and 9 miles south of the Iron Mountain mine. This parcel is adjoined on the north by a tract known as the Otto, the east-west property line being somewhat less than 2 miles north of Llano River.

Iron ore has been found at several places along a zone trending north by northeast, about 500 feet in width and nearly 7,000 feet in length. A shaft in the extreme southwest corner of the Otto tract encountered magnetite, which represents the most northerly known extension of the Bader ore range. Farther to the northwest there is no evidence

[a] Sampled by and analyzed for Robert Linton, of Atwater, Linton & Atwater, mining engineers.

of any exploratory work such as trenches, and careful search on the part of the geologists failed to reveal so much as a fragment of magnetite beyond the west line of the Otto tract. That the ore may continue in this direction is thought to be possible but improbable.

No importance can be attached to any suggestion that might be made in the direction of correlating the Bader range with other occurrences of magnetite in Llano County. There is certainly no adequate reason for regarding the range as in any way the extension of the Iron Mountain ore. Though the trend of the range would carry it to the ore on the Epperson tract, 3 miles to the northwest, there is a wide area of intrusive granite north of the Bader, and beyond this intrusion the structural trends are northerly rather than northwesterly.

Aside from very shallow pits or trenches at various points, the Bader range has been explored only near its north end, where the original surface indications appear to have been the best. Here trenches and float ore extend for a total distance of 1,000 feet in a southerly direction from the Otto shaft. Two lines of outcrop about 80 feet apart are noted in the vicinity of the Bader incline.

About 110 feet south of the incline an excavation in the lower ore ayer shows 31 inches of fairly clean ore dipping about 30° NE. There is also a 5-inch rider lying 2 feet above the principal ore layer and separated from it by feldspathic gneiss. In an adjacent opening on the upper layer the grain or layering of the ore appears to be nearly horizontal.

The Bader incline reveals two ore layers estimated to lie between 10 and 15 feet apart. The dip of these layers varies from 20° to 40°. The lower ore may be described as gneiss carrying thin and discontinuous layers of magnetite. This lean material is not more than 16 inches thick. The incline follows the dip of this ore for about 25 feet and then flattens so that the workings cut across the layering of the gneiss and encounter the upper ore bed. As exposed in the sides of the incline this second layer has a maximum thickness of 20 inches.

The dip length of the incline is estimated to be about 50 feet. All the ore on the dump is layered to a marked degree, much of it being sharply segregated into layers of more or less granular magnetite and of silicate minerals.

To one standing on the surface it seems likely that the lower of the two layers shown in the pits mentioned above is identical with the upper of the two opened by the incline, though this identification may not be affirmed. If it is correct there are at least three ore layers at this place, the lowest being nowhere exposed at the surface.

No definite conclusion concerning the possibilities of the Bader tract can be offered. Compared with the great cropping and abundant float at Iron Mountain, the surface showings would seem at first thought to be unimportant. It is believed, however, that caution should be exercised in accepting an unfavorable view with regard to deposits of the sort here presented, for experience in other districts has shown that the importance of magnetite ore bodies in gneisses may be seriously misjudged from surface indications. It is suggested that the Bader tract is worthy of more extensive exploration than it has received up to the present time, and particularly that preliminary work in this direction should include a refined magnetic survey of the range, which, as already stated, has a length of about 7,000 feet. It is thought that magnetometer observations might give indications of ore in the covered territory between the two ends of the Bader range.

IRON MOUNTAIN.

The Iron Mountain prospect is located 12 miles northwest of Llano and about 1 mile northwest of Valley Spring. The property, consisting of 640 acres, is owned by Robert Downman, of New Orleans. The ore body caps a low mound slightly above the elevation of the surrounding country and trends about N. 60° W. in a slightly curving line. The surface outcrop has a length of about 114 feet and a width of 22 feet at its center. It is slightly narrower at the northwest end and narrows down to about 6 feet at the southeast end. A granite intrusion cuts across the mass at the northwest end, apparently cutting off the ore. The surface cover prevents observations on the southeast end.

The ore body as revealed at the surface is a nearly vertical mass of very pure magnetite. Along its south side schists are exposed in several small cuts. They strike northwest with the ore, but in dip do not accord with the dip of the mass. On the north side a gneissoid rock of granitic type is observed. It is believed to be intrusive into the ore, but is an older intrusion than the granite which cuts across the northwest end. Unfortunately the surface cover has rendered the exact surface relations of the ore body obscure. The complex intrusion of granite into the schists, a condition described in an earlier part of this report, has at this locality also obscured the original relations of the ore to the inclosing rock.

A shaft was sunk near the southwest wall of the ore body. A crosscut has been driven at the 50-foot level, showing 25 feet of solid ore. This crosscut was continued for 54 feet. After passing through the 25 feet of ore a narrow mass of granitic schistose material was encountered, beyond which ore was again found. This second body was confined largely to the floor, and a winze was sunk in ore.

At the 100-foot level crosscuts and drifts were run, but ore was not encountered directly beneath the main mass. The country rock is a mixture of schist and granite. A raise from the 100-foot level connecting with the winze revealed 16 feet of ore in a body of schist dipping at a low angle to the east and grading downward into lean ore and granite.

The relations described above are due, it is believed, to faulting and will be described in detail with cross sections in the later report.

The important fact brought out by the development is the existence of the 16-foot bed dipping in an easterly direction at a low angle. The faulting accounts for the abrupt termination of the vertical bed.

Besides the development by shaft and tunnels above described, the property has been and is being prospected by several diamond-drill holes.

The following is a table of analyses of the Iron Mountain ore.

Analyses of ore from Iron Mountain, Texas.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Metallic iron	65.40	67.60	65.45	66.530	64.90	58.87	61.45	67.70	66.10	63.23	66.82
Phosphorus	.069	.093	.061	(a)	(a)	(a)	(a)	.045	.034	.008	Trace.
Silica	4.695	4.690								4.70	4.65
Sulphur										Trace.	.30
Specific gravity	4.724	4.677									

a Not determined.

1. General sample of surface ore; private report of E. V. d'Invilliers.
2. Sample 125 pieces of ore at depth of 50 feet in shaft; E. V. d'Invilliers.
3. Surface ore sampled by McCreath, clippings of large bowlders; E. V. d'Invilliers.
4. Surface ore, main exposure, sampled by representative of McCreath, 1889; E. V. d'Invilliers.
5. From shaft 8 feet deep, south side of main exposure, sampled by representative of McCreath; E. V. d'Invilliers.
6. From shaft 12 feet deep north side of main exposure, sampled by representative of McCreath, lower 8 feet of ore; E. V. d'Invilliers.
7. From cut 4 feet deep 150 yards east of main exposure, sampled by representative of McCreath; E. V. d'Invilliers.
8. From shaft at main exposure, ore from lower depth than Nos. 5 and 6, chiefly magnetic; E. V. d'Invilliers.
9. Iron Mountain tract, sampled and analyzed by Rattle & Nye; E. V. d'Invilliers.

10, 11. Iron Mountain mine, 50-foot level, taken by Robert Linton, for Johnston, Elliot & Co., of Dallas, Tex.

It would seem advisable to confine prospecting in this area largely to the north side of the line of strike of the ore body. If it can be shown that the flat bed has considerable extension in a northwest-southeast direction and also on the dip, a large body of ore may be present. If underground work is to be continued, it would seem advisable to make a raise from the end of the east drift on the 100-foot level at the point where a disconnected mass of iron was struck, to discover the presence or absence of the bed above. A careful magnetic survey of the territory adjacent to the ore body would be valuable.

VICINITY OF CASTELL.

In Mason County, about 4½ miles south and somewhat west of Castell, magnetite float and ore outcrops occur at several places within the drainage basin of Keyser Creek, also known as Old Place Creek.

Magnetite occurs also at several localities north and northwest of Castell in lean ore beds.

LIVELY TRACT.

The Lively property lies somewhat more than a mile southeast of Iron Mountain and three-fourths mile southwest of Valley Spring. There has been no development work here and the showing is confined to magnetite float in the wagon road northeast of Johnson Creek. This locality is near a line joining the ore at Iron Mountain, to the northwest, and the Becton ore, 4 miles to the southeast. Although the three localities are thus in alignment there is no adequate basis for the suggestion of any connection between these deposits or for any expectation that intermediate deposits are likely to be discovered.

SECTION 13 AND VICINITY.

The tract of 640 acres known as H. and G. N., sec. 13, lies about 4 miles south of the Iron Mountain property, on the southwest side of San Fernando Creek, at the mouth of Willow Creek. Magnetite has been found at several places on this tract and at several localities in the neighborhood on both sides of San Fernando Creek.

ORIGIN.

A discussion of the origin of the iron ores described in outline above will be reserved for the later report. It is believed that they represent metamorphic sedimentary deposits and in general resemble certain of the magnetite deposits occurring in metamorphic rocks in the Eastern States.

PRACTICAL CONSIDERATIONS.

How much iron ore must be assured to warrant the undertaking of mining operations in the Llano field? Though this very practical question may not be answered categorically or with any great degree of confidence, certain assumptions may be made and discussed to indicate the factors of the problem. It may be assumed that an iron mine located in the district should produce 100 tons a day or 30,000 tons a year of 60 per cent iron ore in order to find a ready market for its output and to insure moderate mining cost per ton. This amount would supply from one-third to one-half the ore required by a modern blast furnace. It may be assumed also that the life of the mine must be eight years. The size of an ore body to yield 8 times 30,000, or 240,000, tons must be 2,400,000 cubic feet, on the supposition that the ore measures 9 cubic feet to the ton and that 10 per cent must be left for pillars in the mine. With an average thickness of 10 feet, a mass of ore of the size specified must have a length of say 600 feet and a depth of 400 feet.

Leaner ores susceptible of enrichment by means of magnetic concentrators must be present in correspondingly larger masses to warrant profitable operations.

That bodies of iron ore fulfilling the above-stated moderate assumptions as to size and grade are present anywhere in the Llano district remains to be proved by more extended explorations than have been made up to the present time. It may be said that the geologic work in the district has not led to particularly favorable impressions of the possibilities of these ores, though the question is still an open one which must be practically decided by means of pits, shafts, and carefully placed diamond-drill holes.

SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey or by members of its staff are listed below. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the monographs from either that official or the Director of the Survey. In addition to these papers, several geologic folios contain descriptions of iron-ore deposits of more or less importance.

BALL, S. H. The Hartville iron ore range, Wyoming. In Bulletin 315, pp. 190–205. 1907.

——— Titaniferous iron ores of Iron Mountain, Wyoming. In Bulletin 315, pp. 206–212. 1907.

BARNES, P. The present technical condition of the steel industry of the United States. Bulletin 25. 85 pp. 1885. 10c.

BAYLEY, W. S. The Menominee iron-bearing district of Michigan. Monograph XLVI. 513 pp. 1904. $1.75.

BAYLEY, W. S., and others. Passaic folio (No. 157), Geol. Atlas U. S. 1908. 25c.

BIRKINBINE, J. The production of iron ores in various parts of the world. In Sixteenth Ann. Rept., pt. 3, pp. 21–218. 1894. $1.20.

BOUTWELL, J. M. Iron ores in the Uinta Mountains, Utah. In Bulletin 225, pp. 221–228. 1904. 35c.

BURCHARD, E. F. The iron ores of the Brookwood district, Alabama. In Bulletin 260, pp. 321–334. 1905. 40c.

——— The Clinton or red ores of the Birmingham district. In Bulletin 315, pp. 130–151. 1907.

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——— Tonnage estimates of Clinton iron ore in the Chattanooga region of Tennessee, Georgia, and Alabama. In Bulletin 380, pp. 169–187. 1909.

BURCHARD, E. F., BUTTS, CHARLES, and ECKEL, E. C. Iron ores, fuels, and fluxes of the Birmingham district, Alabama. Bulletin 400. 204 pp. 1910.

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CLEMENTS, J. M., SMYTH, H. L., BAYLEY, W. S., and VAN HISE, C. R. The Crystal Falls iron-bearing district of Michigan. In Nineteenth Ann. Rept., pt. 3, pp. 1-157. 1898. $2.25.

——— The Crystal Falls iron-bearing district of Michigan. Monograph XXXVI. 512 pp. 1899. $2.

DILLER, J. S. Iron ores of the Redding quadrangle, California. In Bulletin 213, pp. 219-220. 1903. 25c.

——— So-called iron ore near Portland, Oreg. In Bulletin 260, pp. 343-347. 1905. 40c.

ECKEL, E. C. Utilization of iron and steel slags. In Bulletin 213, pp. 221-231. 1903. 25c.

——— Iron ores of the United States. In Bulletin 260, pp. 317-320. 1905. 40c.

——— Limonite deposits of eastern New York and western New England. In Bulletin 260, pp. 335-342. 1905. 40c.

——— Iron ores of northeastern Texas. In Bulletin 260, pp. 348-354. 1905. 40c.

——— The Clinton hematite. In Eng. and Min. Jour., vol. 79, pp. 897-898. 1905.

——— The iron industry of Texas, present and prospective. In Iron Age, vol. 76, pp. 478-479. 1905.

——— The Clinton or red ores of northern Alabama. In Bulletin 285, pp. 172-179. 1906. 60c.

——— The Oriskany and Clinton iron ores of Virginia. In Bulletin 285, pp. 183-189. 1906.

HARDER, E. C. Manganese deposits of the United States; with sections on foreign deposits, chemistry, and uses. Bulletin 427. (In press.)

——— Manganese ores. In Mineral Resources U. S. for 1907, pt. 1, pp. 87-110. 1908. $1.00.

——— The Taylor Peak and Whitepine iron-ore deposits, Colorado. In Bulletin 380, pp. 188-198. 1909.

——— The iron ores of the Appalachian region in Virginia. In Bulletin 380, pp. 215-254. 1909.

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——— Iron ores, pig iron, and steel. In Mineral Resources U. S. for 1908, pt. 1, pp. 61-134. 1909.

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HAYES, C. W., and ECKEL, E. C. Iron ores of the Cartersville district, Georgia. In Bulletin 213, pp. 233-242. 1903. 25c.

HOLDEN, R. J. The brown ores of the New River-Cripple Creek district, Virginia. In Bulletin 285, pp. 190-193. 1906. 60c.

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——— The geology of the Cuyuna iron range, Minnesota. In Econ. Geology, vol. 2, pp. 145–152. 1907.

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SPENCER, A. C. The iron ores of Santiago, Cuba. In Eng. and Min. Jour., vol. 72, pp. 633–634. 1901.

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Van Hise, C. R., Bayley, W. S., and Smyth, H. L. Preliminary report on the Marquette iron-bearing district of Michigan. In Fifteenth Ann. Rept., pp. 477–650. 1894.

——— The Marquette iron-bearing district of Michigan, with atlas. Monograph XXVIII. 608 pp. 1897. $5.75.

Weeks, J. D. Manganese. In Sixteenth Ann. Rept., pt. 3, pp. 389–457. 1895. $1.20.

Wolff, J. E. Zinc and manganese deposits of Franklin Furnace, N. J. In Bulletin 213, pp. 214–217. 1903. 25c.

ALUMINUM ORES.

SURVEY PUBLICATIONS ON ALUMINUM ORES—BAUXITE, CRYOLITE, ETC.

The following reports published by the Survey or by members of its staff contain data on the occurrence of aluminum ores and on the metallurgy and uses of aluminum. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the folios from either that official or the Director of the Survey.

BURCHARD, E. F. Bauxite and aluminum. In Mineral Resources U. S. for 1906, pp. 501–510. 1907. 50c.

CANBY, H. S. The cryolite of Greenland. In Nineteenth Ann. Rept., pt. 6, pp. 615–617. 1898.

HAYES, C. W. Bauxite. In Mineral Resources U. S. for 1893, pp. 159–167. 1894. 50c.

——— The geological relations of the southern Appalachian bauxite deposits. In Trans. Am. Inst. Min. Eng., vol. 24, pp. 243–254. 1895.

——— Bauxite. In Sixteenth Ann. Rept., pt. 3, pp. 547–597. 1895. $1.20.

——— The Arkansas bauxite deposits. In Twenty-first Ann. Rept., pt. 3, pp. 435–472. 1901.

——— Bauxite in Rome quadrangle, Georgia-Alabama. Geol. Atlas U. S., folio 78, p. 6. 1902. 25c.

——— The Gila River alum deposits. In Bulletin 315, pp. 215–223. 1907.

HUNT, A. E. In Mineral Resources U. S. for 1892, pp. 227–254. 1893. 50c.

PACKARD, R. L. Aluminum and bauxite. In Mineral Resources U. S. for 1891, pp. 147–163. 1892. 50c.

——— Aluminum. In Sixteenth Ann. Rept., pt. 3, pp. 539–546. 1895. $1.20.

PHALEN, W. C. Bauxite and aluminum. In Mineral Resources U. S. for 1907, pt. 1, pp. 693–705. 1908. $1.00.

——— Bauxite and aluminum. In Mineral Resources U. S. for 1908, pt. 1, pp. 697–708. 1909.

SCHNATTERBECK, C. C. Aluminum and bauxite [in 1904]. In Mineral Resources U. S. for 1904, pp. 285–294. 1905. 50c.

SPURR, J. E. Alum deposits near Silver Peak, Esmeralda County, Nev. In Bulletin 225, pp. 501–502. 1904. 35c.

STRUTHERS, J. Aluminum and bauxite [in 1903]. In Mineral Resources U. S. for 1903, pp. 265–280. 1904. 70c.

ASPHALT.

SURVEY PUBLICATIONS ON ASPHALT.

The following list comprises the more important papers relative to asphalt published by the United States Geological Survey or by members of its staff. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.:

Anderson, Robert. An occurrence of asphaltite in northeastern Nevada. In Bulletin 380, pp. 283-285. 1909.

Boutwell, J. M. Oil and asphalt prospects in Salt Lake basin, Utah. In Bulletin 260, pp. 468-479. 1905. 40c.

Day, W. C. The coal and pitch coal of the Newport mine, Oregon. In Nineteenth Ann. Rept., pt. 3, pp. 370-376. 1899. $2.25.

Eldridge, G. H. The uintaite (gilsonite) deposits of Utah. In Seventeenth Ann. Rept., pt. 1, pp. 909-949. 1896.

——— The asphalt and bituminous rock deposits of the United States. In Twenty-second Ann. Rept., pt. 1, pp. 209-452. 1901.

——— Origin and distribution of asphalt and bituminous-rock deposits in the United States. In Bulletin 213, pp. 296-305. 1903. 25c.

Hayes, C. W. Asphalt deposits of Pike County, Ark. In Bulletin 213, pp. 353-355. 1903. 25c.

Taff, J. A. Albertite-like asphalt in the Choctaw Nation, Indian Territory. Am. Jour. Sci., 4th ser., vol. 8, pp. 219-224. 1899.

——— Description of the unleased segregated asphalt lands in the Chickasaw Nation, Indian Territory. U. S. Dept. Interior, Circular 6. 14 pp. 1904.

——— Grahamite deposits of southeastern Oklahoma. In Bulletin 380, pp. 286-297. 1909.

——— Asphalt, related bitumens, and bituminous rock. In Mineral Resources U. S. for 1908, pt. 2, pp. 707-715. 1909.

Taff, J. A., and Smith, C. D. Ozokerite deposits in Utah. In Bulletin 285, pp. 369-372. 1906. 60c.

Vaughan, T. W. The asphalt deposits of western Texas. In Eighteenth Ann. Rept., pt. 5, pp. 930-935. 1897.

STRUCTURAL MATERIALS.

GENERAL.

FIELD INVESTIGATIONS OF STRUCTURAL MATERIALS.

By Ernest F. Burchard.

In connection with the work of testing structural materials for the use of the Government at the laboratories of the United States Geological Survey at St. Louis, Mo., from September, 1904, to April, 1909, and since then at Pittsburg, Pa., large quantities of sand, gravel, and crushed stone have been needed from time to time, besides samples of building stone, clays, and other quarry products. In many instances it has been necessary to obtain single samples of sand, gravel, or crushed stone in lots of 1 to 3 carloads.

For obvious reasons all these collections have had to be made by a Survey representative. As the work progressed it was found essential that numerous geologic data should be gathered regarding the material collected, in order that it might be properly classified as to character, source, geologic age, etc.; that it might be rated according to quantity available, nearness to transportation lines, approximate costs, suitability for special purposes, etc.; and that notes might be taken regarding undeveloped deposits of possible value. Furthermore, it was desired that the selection of materials for tests should be made broadly, in order to obtain, first, representative types of material, and later, if possible, typical materials of the more important building centers in the United States. In order to secure a certain degree of uniformity in this work and economy of effort and expense, it was decided to have as much of the sampling as was practicable done by a geologist whose regular field trips could be combined conveniently with those necessary for obtaining materials for the laboratory. During parts of the last three years several geologists, including the writer, have been engaged in field work of this sort.

The results of the field and laboratory investigations of structural materials are intended primarily for the information of those departments of the Government that are engaged in construction work, namely, the office of the Supervising Architect of the Treasury Department; the War Department, which has charge of the river and harbor improvements and the building of fortifications and barracks; the Isthmian Canal Commission; the Reclamation Service, under the Department of the Interior; and the Navy Department, under which is the Bureau of Yards and Docks. The field and test data have been made available to these departments, although comparatively little of the information has yet been published. However, when fairly complete information has been obtained that is thought to be of general interest it has been compiled and published. The principal reports along these lines are given in the bibliographies at the ends of the chapters on stone, cement and concrete, and other structural materials in this bulletin.

Before the fiscal year 1909–10 the making of general typical collections and of special areal studies was the principal work undertaken. In the spring of 1909 a request was received by the Director of the Survey, through the Secretary of the Interior, from the Secretary of the Treasury, accompanied by a list of about 380 cities in which Congress had authorized the construction of new federal buildings and extensions on which work would be in progress in various stages within the next three or four years. This work will involve an expenditure of more than $50,000,000. The following quotations from this request are therefore of interest here:

> It will be in the interest of the Government to have the Geological Survey furnish this Department with information as to the character and extent of the sands, gravels, stone, and other materials suitable for work in concrete construction; sands for mortars; stone for masonry work; brick, terra cotta, hollow tile, and other structural materials that may be suitable and available for use in the construction of these buildings within easy reach of each of the localities named in this list. Exact and thorough data of this kind will not only be of great service in connection with the construction of the buildings in question, but also in the preliminary planning of them.
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> Reports should be submitted to the Supervising Architect's office from time to time, as rapidly as any part of this work can be completed or definite results obtained, without awaiting publication, in order that this information may be available for use in the planning and construction of public buildings already authorized.

In view of the urgency of this request, it became necessary to make this work a special order of business, rather than incidental to other field trips. Therefore, during the last half of 1909 part of the time of six geologists and all the time of the writer was spent on this work, with the result that about 85 per cent of the 380 specified localities, including all the urgent cases, were visited, and a preliminary field report on each one was prepared and sent to the Supervising Architect.

At the outset it was planned that there should be uniformity in the reports, and therefore they were prepared mostly according to the following outline, care being taken that only data of a practical character should be given:

Structural materials investigated for use in federal buildings.

I. Stone:
 A. Dimension stone for exterior—
  a. Foundations.
  b. Walls.
  c. Sills and trim.
 B. Ornamental stone for interior (marble, serpentine, onyx, etc.).
 C. Slate for roofing, sanitary fixtures, etc.
II. Material for concrete:
 A. Sand.
 B. Gravel.
 C. Crushed stone, slag, cinder, shell, etc.
 D. Cement (Portland, natural, hydraulic, etc.).
III. Clay products:
 A. Brick—
  a. Common.
  b. Front (pressed, rough, fire-faced, etc.).
 B. Tile—
  a. Roofing.
  b. Hollow building tile or block.
IV. Materials for mortars and plasters:
 A. Lime—
  a. Quick.
  b. Hydrated.
 B. Gypsum wall plasters.
 C. Sand.

Necessarily the work was done very rapidly, and the reports were written not for the use of geologists, but rather for that of persons who may not have had training in geology. The points of interest to the geologist, however, such as the nature, extent, quality (as to uniformity, durability, color, etc.), location (as to means of handling and transportation), structure, and geologic relations in general that affected the use of materials, were borne in mind throughout the series of reports. All except two of the reports ranged in length from 1 to 10 or 12 typewritten pages, but averaged less than 5 pages.

In these field studies the endeavor was to relieve the laboratory of all the work possible and to give the Supervising Architect a definite opinion as to the value and availability of a material, backed up by a detailed description of it and the results of simple field tests. In addition, use was made of any authentic test data in possession of the producer or contained in state geological survey reports. The common points considered with regard to stone, gravel, clay, gypsum, etc., were noted on special forms in loose-leaf books. Many special details had to be considered with regard to the various materials, and for brick and other clay products notes of a special form were kept regarding the processes of manufacture. Sands were subjected to qualitative tests for the presence of lime, alkali, clay, magnetite, quicksand, and silt. Granularmetric analyses were made and the material was critically examined under the field lens.

A knowledge of the Supervising Architect's general specifications was requisite, and after a little practice the geologist was able to tell in most cases, after a careful investigation, whether a sand, gravel, stone, or brick would fulfill these specifications or not.

If the question should be asked, of what direct advantage are these reports to the Supervising Architect or to federal construction work in general, the answer may be summarized as follows:

1. Attention is called to materials of merit which, owing to their proximity to the building site, should be obtainable at lower prices than similar materials from long distances.

2. Attention is called to little-developed and hitherto comparatively unknown materials that may possess special merit for certain kinds of work.

3. Warning is issued against the use of materials that are not suitable yet that are commonly used in certain localities.

4. Warning is issued against the acceptance of materials from deposits which may be of good quality but of insufficient quantity.

5. Warning is issued against the acceptance of materials from deposits which may afford excellent material in small samples, but whose quality in adequate quantities is irregular and inferior.

6. Data regarding local costs and freight rates are obtained on small and large lots of all materials shipped into the locality, such as cement, stone, sand, wall plasters, etc., thus affording aid toward preparing specifications for new buildings.

7. Some attention was paid to the proposed federal building sites, with reference to character and condition of the ground on which foundations would have to rest and with reference to the smoke conditions.

In addition to the results of this work as related to the Government, its relation to the country at large may be mentioned. When little-known but meritorious materials are thus brought to the attention of the Supervising Architect, and incidentally to that of the public, as they doubtless will be brought later by use in federal buildings and by published reports, the efficient use of important natural resources is encouraged. In many instances during the past field season, materials that would probably otherwise have been passed unnoticed have been brought to the attention of the Supervising Architect. Many such instances might be noted, but the following are fair samples showing the range of such materials covered.

1. Large and sound glacial bowlders that occur in great abundance in the vicinity of Minot, N. Dak., a region otherwise devoid of stone. These bowlders can be split and trimmed into handsome, massive dimension stones.

2. The "chats" or tailings from the concentrating mills in the Plattville, Wis., zinc district, from the copper smelter at Great Falls, Mont., etc. These chats make an excellent aggregate for both plain and reinforced concrete work, and the tailings from the Great Falls smelter make good sand for mortar and brick.

3. Sandstones used locally at Carrollton and Warrensburg, Mo., and Big Stone Gap, Va.

4. Oolitic limestone at Bowling Green, Ky.

5. Subcrystalline limestone at Batesville, Ark., Frankfort, Ky., and Harriman, Tenn.

6. Shale near Mansfield, Ohio, suitable for brick making.

7. Loam at various points in the Mississippi embayment in Arkansas, Mississippi, and Tennessee, suitable for the manufacture of brick.

8. Sand and gravel from points on Arkansas River in Kansas and Oklahoma, very similar in quality to the well-known Kaw River sand.

Besides the work outlined above, there have been carried on at times during the past year at the laboratories of the Survey, in Pittsburg and Washington, special investigations of such subjects as the manufacture and the hydration of lime and studies of Keene cement and wall plasters, tending toward the formulation of standard specifications for these materials in government construction work. Here again the services of field geologists have been required and the geologic records of the Survey thereby enriched. Incidentally to their regular field work several geologists have visited areas containing developed and undeveloped deposits of granite, slate, Portland cement materials, and gypsum, and the following papers are either direct or incidental results of the work of the past field season. The papers on materials available at Minneapolis, Minn., and at Austin, Tex., excluding the section on cement materials, are examples of the most comprehensive reports made to the Supervising Architect and are given here in substance for the sake of the general information they contain as to typical areas both within and outside of the region of glacial drift.

STRUCTURAL MATERIALS AVAILABLE IN THE VICINITY OF MINNEAPOLIS, MINNESOTA.

By Ernest F. Burchard.

INTRODUCTION.

Within the city limits or a few miles outside of Minneapolis, Minn., are plentiful supplies of limestone for rubble and range rock and for crushed stone; sand and gravel for concrete and mortar; and clay for common building and hollow brick and for fireproofing ware.

The region is within the Wisconsin glacial-drift sheet, and the city is built for the most part on a sand and gravel foundation, but along Mississippi River and at a few places in the northeast section of the city limestone outcrops near enough to the surface to be quarried. As no stone suitable for high-class dimension or cut stone work is available in the city, and as there are areas in Minnesota within 100 miles of Minneapolis which produce granite, sandstone, and magnesian limestone, all of which are used to a considerable extent for handsome buildings in Minneapolis and St. Paul, brief notes will be given on the rocks available at St. Cloud, Ortonville, Kettle River, Kasota, and Mankato.

STONE.

DIMENSION STONE.

GRANITE.

Minnesota is well supplied with granite suitable for building purposes. The two principal granite areas are near St. Cloud and Ortonville, respectively 65 and 179 miles northwest and west of Minneapolis.

St. Cloud granites.—In the vicinity of St. Cloud three kinds of granite are quarried. One is a pinkish-gray medium-grained stone, from which the new federal building at St. Paul has been constructed. The qualities of this stone are therefore well known to the Supervising Architect's office. The Minnesota Geological Survey reports that the gray quartzose syenite from East St. Cloud showed a crushing strength of 26,250 pounds per square inch on "bed" and of 25,750 pounds per square inch on "edge." The ratio of absorption was 1:208. The coarse-grained pinkish-gray granite in the basement of the new capitol building at St. Paul is reported to have been obtained at St. Cloud. There are also fine-grained gray syenites quarried at St. Cloud, and a red syenite. The fine-grained gray rock showed crushing strengths of 28,000 pounds and 26,250 pounds per square inch, respectively on "bed" and on "edge." The red syenite showed practically the same results. The prices of the St. Cloud stone in rough blocks is reported to range from 75 cents to $1.25 per cubic foot.

"Ortonville" granite.—In western Minnesota, near Ortonville, is a dark-red granite that has been used to considerable extent for structural and ornamental purposes in both Minneapolis and St. Paul. There are several columns of polished "Ortonville" granite in the capitol at St. Paul, and the exterior of the handsome city hall and county court-house building at Minneapolis, erected at a cost reported to have been $2,250,000, is faced with dark-red "Ortonville" granite. This stone is rather coarse grained and is capable of being quarried in massive blocks. Of late, however, little has been quarried.

SANDSTONE.

Kettle River.—At the town of Sandstone, on Kettle River and the Great Northern Railway, 87 miles north-northeast of Minneapolis, are large quarries in sandstone, probably of Cambrian age. Two firms operate quarries here, the Kettle River Quarries Company and the Barber Asphalt Paving Company. The rock quarried is a fine-grained light-pink or salmon-colored stone, generally very hard and durable. The sand grains are sharp and many of them sparkle and show recrystallized faces. The relative size of the grains may be indicated by the following sieve tests, which were made on sand derived by crushing the rock until it had been reduced to its individual grains: Remained on 20-mesh, none; on 40-mesh, 30 per cent; passed through 40-mesh, 70 per cent. The cementing material is mainly silica. There are some beds, especially toward the top of the quarry, in which the rock is of a darker shade, varying in color from yellow to brownish red. The face of the Kettle River Company's quarry is about 80 feet high and about 2,200 feet long. Only about 20 feet of stone is selected as the choicest building stone, much of the upper courses being utilized for paving blocks and for heavy masonry. The rock lies in massive beds, 1 to 3 feet thick, and there are three thin zones of shaly sandstone, 16 to 20 feet apart, that divide the quarry face vertically into four divisions. The beds dip 2° to 4° SE. and are jointed in places by well-marked vertical joints that facilitate quarrying but do not prevent blocks 5 to 10 feet long from being easily obtained. This quarry is operated on a large scale and is equipped with all the facilities necessary for a large output of stone, such as electric power, compressed-air drills, 25 large loading derricks, two locomotives, many cars, and several miles of standard track connecting with the Great Northern Railway at Sandstone. There is a large sawmill and cutting shed where dimension stone is cut to order, and the stone, although hard, has been found to be adapted to the highest grade of carved work. For this purpose it rivals granite and is in some respects superior, particularly with reference to its fineness of grains. The rock has a very high crushing strength, tests having been made at the Watertown Arsenal that showed 12,295 and 12,799 pounds per square inch. A chemical analysis made at the same laboratory shows silica, 97.10 per cent; alumina, 2.20 per cent; lime, 0.60 per cent; and magnesia, 0.10 per cent. The stone works very freely, although it shows stratification very faintly, if at all, and contains no fossils. Although there is considerable stripping, such as soil and disintegrated or shaly sandstone, the quarry floor is kept free of rubbish. Nearly all the waste material is utilized in one way or another. Even the sand screened from the crusher is saved. The principal products of the Kettle River Quarries Company are building stone, sawed stone, crushed rock, rubble, paving blocks, curbing, cross walks, bridge stone, coping, and monument bases.

The library building at the University of Illinois was built of this sandstone in 1896. After fourteen years of exposure the stone in this building shows almost the same brightness that it did when first laid in the wall. The stone is chemically so inactive that artificial gases, cements, and other agents that discolor most stones seem to have little or no deleterious effect on it. Other buildings in which the stone has been used are the United Presbyterian Church (interior) at Worcester, Mass.; Spokane Club building, Spokane, Wash.; Des Moines (Iowa) public library; court-houses at Elk Point, S. Dak., Crookston, Grand Rapids, and Benson, Minn., etc. A school building constructed of the stone at Sandstone, Minn., was recently burned out, and the outer walls showed very little effects of the fire. The spalling that occurred was mostly in the window caps and along the coping.

Practically all the virtues of granite appear to be characteristic of this sandstone, with the added advantage of lower cost. Approximate prices quoted are: Rock-faced dimension stone, $1 to $1.25 per cubic foot, f. o. b. the quarries; tool-faced stone, $1.25 to $1.75 per cubic foot; sawed stone, two sides, 50 cents per cubic foot; mill blocks, No. 1, 35 cents per cubic foot; rubble, $1 per cubic yard; and paving blocks, $1.50 per cubic yard.

MAGNESIAN LIMESTONE.

The nearest quarries of a high-grade magnesian limestone that can be tool faced, carved, polished, etc., are at Kasota and Mankato, Minn. Although the stone at both places belongs to the same formation, that at Kasota is more worked for cut stone. The Mankato stone is of a buff color, and that at Kasota is of a light-pink shade, banded faintly in places. The Mankato stone is used largely for massive masonry and as crushed stone, whereas that at Kasota is used for finer building purposes. The stone is a fine-grained, highly magnesian limestone. At Kasota there are quarries operated by the Breen Stone Company and by Babcock & Wilcox. The beds range from a few inches thick at the top (the thinness is due to weathering) to about 4 feet thick below. Massive blocks 12 feet long may be quarried if desired. The stone is quarried to a depth of about 12 feet below the stripping, which amounts to 3 to 5 feet of sand and gravel. In winter the quarries are closed and the beds covered with straw so as to prevent the stone from being disintegrated by frost. The companies mentioned above have cutting shops at Kasota, at which the stone is sawed, tooled, turned, and polished. The supply of stone here is ample and the facilities for its production are larger than the demand.

The United States post-office building at Aberdeen, S. Dak., is faced with Kasota cut stone, and much of the "marble" wainscoting in the Minnesota state capitol building at St. Paul is of polished Kasota stone.

Tests made by Maj. Q. A. Gillmore before 1875 showed this stone to have a crushing strength of 10,700 pounds per square inch on "bed;" specific gravity, 2.63; weight per cubic foot, 164.4 pounds; and ratio of absorption, 1.56.

Present approximate prices at Kasota are: Cut stone, tool faced, $1.25 per cubic foot; polished work—yellow mottled, 75 cents per square foot, and pink mottled, 50 cents per square foot.

RUBBLE AND RANGE ROCK.

The local surface rock at Minneapolis is the "Trenton" limestone. This rock consists of beds of high-calcium, fine-grained, dense light-gray rock, beds of bluish to greenish argillaceous magnesian limestone, and beds that approach shale in texture. The first-mentioned beds are the most desirable for all purposes, but most of the quarries are obliged to move considerable of the inferior stone and more or less of it is worked into the product. In the vicinity of Fifteenth avenue northeast, between Central street and Johnson street, about 1¾ miles northeast of the new post-office site, is an area comprising about 60 acres which supports a large quarrying industry. There are three large quarries operating here, the output of which is mostly crushed stone. These crusher quarries will be described later (p. 287). At the east side of this area is one quarry, that of the A. P. Anderson Stone Company, adjoining the opening of the Minnesota Stone Company, where rubble, heavy blocks, and riprap are quarried. The best material lies at a depth of 18 or 20 feet from the top of the rock and is 8 to 10 feet thick above the base of the quarry. The rock is hard, fine-grained to subcrystalline, wavy bedded, blue-gray limestone. Stone 6 to 15 inches thick and 5 to 6 feet in length are commonly obtained and blocks 3 feet thick are available. This rock is sold mostly for footings in large structures, such as grain elevators. Prices range from $1.70 to $2.50 a perch.

Very high-grade limestone rubble is produced at the quarry of J. A. McLeod, at Second avenue NE. and the Great Northern Railway tracks. About 10 feet of glacial sand and clay overlie the stone, which is fresh, light-gray, fine-grained to subcrystalline, high-calcium limestone. It is sold principally for footings, but the demand is small and much rock that would make good rubble must be run through the crusher.

On the southwest bluff of Mississippi River at two places, near the Milwaukee, St. Paul and Sault Ste. Marie Railway bridge and near Twenty-ninth avenue south, the "Trenton" limestone is quarried for rubble. The quarry near the bridge is operated by Cook Brothers, and quarries in the Twenty-ninth avenue locality are operated by the Riverside Stone Company and by the Twin City Stone Company. The stone is nearly the same at the three river quarries. The upper half is of argillaceous magnesian limestone, which is very soft in places and is termed "soapstone" by the quarrymen. The lower half, generally 12 to 14 feet thick, consists of hard, dense, fine-grained bluish limestone with wavy laminations. This lower rock is the only reliable material in these quarries, and if any rubble is used in the federal building, only hard, blue, high-calcium limestone should be specified. Both rubble and ordinary range stone can be produced from the lower beds in these quarries. Range rock looks well at first, but in a few years the blue color fades to a buff and the laminations become prominent. This is shown in many old-time buildings in Minneapolis. In these river quarries there is only two or three years' supply of stone, because the park board has acquired the river front and has set a limit beyond which the stone may not be quarried into the bluff.

Present prices on stone, delivered, per perch, are for rubble $1.15 and for range $2.85. Sills and dimension stone are sold at about 25 cents per linear foot, 6 inches thick, loaded at the quarry.

MATERIALS FOR CONCRETE.

SAND AND GRAVEL.

The sand and gravel situation at Minneapolis is unique. The city is built largely on deposits of sand and gravel of glacial origin, and for the most part, heretofore, the sand and gravel needed for building purposes have been taken from the excavations for the buildings themselves. The surplus sand and gravel from excavations for small buildings and residences has been hauled away and used in the construction of the large business blocks in the downtown district, which may have required more sand and gravel than could be obtained from their own excavations. Of late the sand business has expanded a little, and in the southern portion of the city, between Mississippi River and the lakes, a number of pits have been opened in the low hills that are characteristic of the topography. When the hills have been leveled the lots are platted and sold for residence purposes. The business of preparing sand and gravel on a large scale has only just started in Minneapolis, but there is great need for a plentiful supply of uniformly clean material. One small plant, where sand is dry screened, has been erected near Lake of the Isles, and a plant to wash and screen sand, projected near Cedar Lake, may be in operation by the summer of 1910.

Efforts were made to ascertain the possibilities of securing supplies of sand and gravel from the excavation that will be necessary if the post-office building is erected on the block now owned by the Government, bounded by Washington avenue, Second street, Second avenue south, and Third avenue south. It was learned that the south half of the block occupies filled ground and that no sand nor gravel may be expected there. Test pits made under the supervision of the custodian of the site, as well as sewer records, show this to be true. Sewer records indicate that there may be 10 or 12 feet of sand and ferruginous gravel in the northern third of the block, and the same opinion is expressed by certain contractors who have erected structures in the vicinity.

Sand from several building excavations in the business part of Minneapolis, near the river, was examined. Nowhere was it of uniform quality. Some silt was invariably present, and the sand was on the average a little too fine for concrete and was not very sharp. Some gravel can be screened out of the sand, but generally it has to be supplemented by crushed stone, as the quantity is insufficient.

Specifications for all sand and gravel used in Minneapolis work should call for screened material, because the run of bank material is not uniformly reliable.

There are several pits in the southern part of the city, southeast of Powder Horn Lake. The pit of E. O. Parker at Thirty-seventh street and Sixteenth avenue south showed several years' supply of material, which consisted mainly of light-gray fine to medium grained sand, with a little small gravel in the upper part and irregular small lenses of torpedo sand and small gravel scattered through the bank. The sand is mainly round and subangular and does not feel sharp. Lime carbonate is present, and some mica and magnetite. There is a little soft, black, carbonaceous matter present in the lenses of torpedo sand, and at various places in the bank small lumps of clay or loam were noted. An average of sieve tests on two samples of sand showed as follows: Passed through quarter-inch mesh, 100 per cent; remained on 20-mesh, 12½ per cent; on 40-mesh, 57 per cent; passed through 40-mesh, 30½ per cent. Soil and loam 1 to 3 feet thick must be stripped from the top, and this work if not carefully done will render the sand very unclean. In the same block with the Parker pit coarser sand had been excavated in building a dwelling, and on the block to the north concrete blocks are being made from the material excavated from a shallow pit showing a larger proportion of small gravel than the Parker pit. It is evident that the material in this vicinity is not uniform in character.

Other outlying pits farther west are worked by Henry Prinz, who hauls 100 to 120 yards of sand a day, of about the kind of material described above. There are several other firms engaged in this business, and the average price of the sand and gravel, delivered, is about $1 per cubic yard.

As stated above, the preparation of sand by mechanical methods has just begun in Minneapolis. One firm, the Nelson Brothers Paving and Construction Company, operates a pit and plant between Cedar Lake and Lake of the Isles, at Dean boulevard and the Chicago, Milwaukee and St. Paul Railway tracks. This firm has 6 acres of sand and gravel, 10 to 20 feet deep. Two pits are open, showing 10 feet or more of gravel, not yet to bottom. An overburden of black soil and brown gravelly clay must be removed to a depth of 2 to 4 feet. The bank shows irregular layers of mixed sand and gravel and layers of sand with little gravel. The sand is grayish to grayish brown and ranges from medium grained to coarse. It is subangular, round, or angular and feels sharp. The sand is clean unless clay gets in from above and ordinarily does not give any stain. Lime is present, and a little magnetite. The sand is mostly quartz but contains some feldspar and other crystalline materials derived from the disintegration of granite and gneiss pebbles and bowlders. Sieve tests on sand passing quarter-inch sieve showed: On 20-mesh, 47 per cent; on 40-mesh, 40 per cent; through 40-mesh, 13 per cent. The proportion of sand in the bank passing quarter-inch screen is about 60 per cent.

The gravel in this bank ranges from small pebbles to cobbles 3 or 4 inches in diameter and small bowlders. The coarser material occurs in the upper parts. The gravel is composed largely of dolomite, with pebbles of granite, gabbro, gneiss, chert, and sandstone and a few of clay shale. Some pebbles of rotten argillaceous limestone and dolomite, as well as decomposed crystalline rock, were noted. The pit is worked on a comparatively large scale, the plant having a capacity of 100 yards a day. The material is screened dry through a rotary double-jacket screen having $1\frac{1}{4}$-inch, $\frac{1}{2}$-inch, and $\frac{1}{4}$-inch apertures. The product is loaded on cars and delivered to yards in the center of the city, whence it is distributed by wagons. Some of the product is used at the plant in the manufacture of concrete blocks and sidewalk slabs.

General prices are, for bank-run material, delivered on the job, $1 a cubic yard, and for screened material, $1.10 a yard.

CRUSHED LIMESTONE.

The "Trenton" limestone that is quarried in the vicinity of Fifteenth avenue NE., between Central street and Johnson street, is converted into crushed stone by three large crushers. These crushers are operated by the Blue Limestone Company, the Minneapolis Crushed Stone Company, and the Minnesota Crushed Stone Company, and their entire output, about 200,000 cubic yards annually, is handled by the Mineral Supply Company, a selling company. The beds quarried by these firms dip gently to the southeast, so that the beds which are quarried by the Blue Limestone Company at the west lie in the bottom of the quarry of the Minnesota Crushed Stone Company at the east. The beds quarried by the Blue Limestone Company consist of a bluish-gray, fine-grained, thin, wavy-bedded limestone, much broken by joints and containing some argillaceous shaly material on the bedding planes. The rock weathers to a grayish-buff color. The material is so badly broken by nature that it is adapted only to being crushed. When it is crushed and well screened a product of excellent grade is obtained. The crushed stone from these wavy limestone beds runs high in calcium carbonate and is the strongest and most durable of the rock exploited here. These beds are about 15 feet thick, and because they dip to the southeast they occupy only the lower two-thirds of the face in the Minneapolis Crushed Stone Company's quarry. They are overlain by a thicker-bedded, argillaceous magnesian limestone. The rock in these upper beds is apparently good and sound, but on account of its composition it does not prove as strong or as durable as the blue limestone. Still farther east, at the pit of the Minnesota Crushed Stone Company, the blue-limestone beds are covered by a greater thickness of argillaceous magnesian limestone. This quarry is deeper than the others, about 28 feet deep, so that the blue limestone is obtainable to the extent of perhaps 40 per cent of the product. All these quarries are operated on a large scale and are equipped for handling the stone by the most improved methods for crushing and screening it thoroughly and for shipping by rail. The products are used for concrete and macadam. The stone is screened to the following sizes: Three-eighths to five-eighths inch, five-eighths to $1\frac{1}{4}$ inches, and $1\frac{1}{4}$ to 2 inches; and the dust is screened through the $\frac{3}{8}$-inch screen. The following prices prevailed in autumn, 1909: Screenings below three-eighths inch, $1.25 per cubic yard; reinforced concrete size, three-eighths inch to $1\frac{1}{4}$ inches, $1.90; and 2-inch size, $1.75, all delivered in the business district, Minneapolis.

One other quarry, that of J. A. McLeod, at Second avenue and the Great Northern Railway tracks, produces crushed stone. As described above, under the head of rubble (p. 284), the rock quarried here is of the best quality of high-calcium limestone, hard, fine grained, and unweathered.

There is an abundance of well-prepared crushed stone in the Minneapolis district, but the principal caution that deserves emphasis here is that specifications should call for hard, fine-grained, blue, pure limestone, free from argillaceous or magnesian limestone. Physically and chemically, the purer limestone is the superior material.

CRUSHED QUARTZITE.

It was reported to the writer that a very hard quartzite occurring at New Ulm, Minn., is crushed and shipped to Minneapolis under the name of New Ulm "granite." None of this stone was found in the city and prices could not be obtained, but from the nature of the stone it should prove to be a very durable and firm-bonding material.

CEMENT.

No Portland cement is made nearer to Minneapolis than Mason City, Iowa. It is reported that the Universal Portland Cement Company supplies 90 per cent of the trade here, the other brands being principally Chicago A A, Marquette, and Northwestern States. Prices ranged in November, 1909, according to quantity, from $1.10 to $1.50 per barrel, with rebate of 40 cents for sacks. The so-called "bricklayer's" cement, or hydraulic cement, made at Mankato and Austin, Minn., is used here in masonry.

CLAY PRODUCTS.

COMMON BRICK.

Large quantities of common brick are made in Minneapolis and the neighboring towns of Chaska and Coon Creek, Minn., and Menominee, Wis. The brick center of Minneapolis is along Mississippi River, near the north city limits. Eleven brickyards are in operation here. On the west side of the river are the Minneapolis Brick and Tile Company

Krafting & Benson, Frank Johnson, S. G. Johnson, and the city workhouse; on the east side of the river are yards of the Minneapolis Brick and Tile Company, St. Anthony Brick Company, Martin Brick Company, St. Paul Brick Company, Anderson Brick Company, and Northwestern Fireproofing Company. All these firms use a blue calcareous clay deposited in the river valley. All the firms make a stiff-mud brick; most of the brick are side cut, but a few firms make an end-cut brick, and one firm produces a sand-mold, soft-mud brick in connection with its other products. The brick are generally burned with wood or by producer gas. They are of a cream color and the kilns contain 20 to 40 per cent of soft brick. Specifications should therefore call for selected, hard-burned brick, rather than "kiln-run" hard brick. Small lime specks were noted in a few brick, but they are not common, and if the brick are selected lime specks can be avoided. The Minneapolis brick will doubtless fulfill the specifications as a brick for backing and inside work. The brick of the Northwestern Fireproofing Company are reported to have been used in the last addition that was made to the present federal building. The price is now about $9 per thousand for hard-burned brick, delivered.

At Coon Creek, about 15 miles north of Minneapolis, on the Great Northern Railway, the Menomonie Press Brick Company operates a yard having a capacity of about 50,000 brick a day during the working season. Light-red to dark-brown pavers and building brick are made at this plant. The clay used is a slightly calcareous brown glacial clay, comparatively free of pebbles. Where pebbles occur, nearly all are removed by the rolls, but occasionally a small silica pebble or a speck of magnesian-lime carbonate shows in the brick. The brick are of the stiff-mud, side-cut type and are generally burned very hard. Hard brick from Coon Creek can be delivered in Minneapolis at about $10 per thousand. The Menomonie Press Brick Company makes at Menominee, Wis., a soft-mud, sand-mold brick, medium to dark red in color, that can be shipped to Minneapolis, 76 miles, and sold f. o. b. Minneapolis at about $10.40 per thousand.

At Chaska, Minn., 23 miles southwest of Minneapolis, the following firms produce common brick: The Chaska Brick and Tile Company, Riedele & Casper, and the G. H. Klein Brick Company. The combined capacity of these firms is nearly 50,000,000 brick a year. Brick from the Chaska Brick and Tile Company were examined at St. Paul. These brick are cream-colored, soft-mud, sand-mold brick, which show a few lime specks and some spalling and are reported to show efflorescence. All the brick from Chaska are said to be of the same general type. They supply nearly all the demand for common brick in St. Paul and are reported to have been used in the United States post-office building, the Minnesota state capitol, the South

Dakota state capitol, and nearly all the brick buildings in St. Paul for thirty-five years. At present the Chaska brick cost in Minneapolis about $7.20 per thousand.

The Princeton Mercantile Company, Princeton, Minn., manufactures both wire-cut and sand-mold cream-colored common brick. Selected stock sells in Minneapolis at $8.20 per thousand.

FACE BRICK.

Face brick are made by the Twin City Brick Company, at St. Paul, Minn., and by the Menomonie Press Brick Company, Menominee, Wis. The Twin City brick are made from Ordovician ("Trenton") blue clay shale, calcareous in places. The brick are all pressed and, according to the stratum of shale from which they are made or according to the combinations of shale employed, are colored light yellow, gray, greenish, red, or brown. Good hard brick can be obtained here in any desired quantity or shape. The prices range from $14 to $100 per thousand.

The Menominee face brick are pressed brick of various shades of red.

FIREPROOFING BLOCKS.

Hollow blocks and hollow brick, called "fireproofing ware," are made in large quantities at North Minneapolis and at Chaska, Minn. The largest producer of these products is the Northwestern Fireproofing Company, of Minneapolis. The blocks are made from blue river clay, according to the stiff-mud process. The blocks are burned in down-draft kilns by wood fire. Sawdust, to the extent of about 25 per cent by volume, is added to the clay. The sawdust burns out, and leaves the blocks lighter in weight and supposedly tougher. They are of a light cream color, spotted in places by pink, especially where underburned.

Among the products of the Northwestern Fireproofing Company are outside wall tile, arch tile, partition tile, column and girder covering, suspended ceiling tile, book tile for metal roofs, and hollow brick. It is reported by this company that its products have been accepted for use in the federal buildings at the following places: Crookston and Fergus Falls, Minn.; Superior, Wis.; and Grand Forks, N. Dak., as well as in the additions to the present federal building in Minneapolis. Several other firms in North Minneapolis, including the Minneapolis Brick and Tile Company, make similar hollow fireproofing ware. The Chaska Brick Company makes hollow brick and reports that its product was used in the federal building at St. Paul, Minn. Hollow brick are reported to be made also by the Princeton Mercantile Company, at Princeton, Minn.

MATERIALS FOR MORTAR AND PLASTER.

Sand.—Sand for Portland cement mortar and for sanding hard-wall plasters can be screened out of the glacial sand and gravel deposits that yield concrete material. The sand in these deposits is, as a rule, rather fine, so that there is no difficulty in obtaining an abundant supply of suitable material.

Wall plaster.—The nearest gypsum mines are at Fort Dodge, Iowa, where all the standard brands of wall plasters are manufactured. Some raw plaster is reported to be shipped from there to Minneapolis, where it is manufactured into plaster.

SAMPLES.

Samples have been sent for test to the Survey laboratories at Pittsburg as follows: From the Breen Stone Company, Kasota, Minn.: (B 50), six 2-inch cubes of pink magnesian limestone. From pit of Nelson Brothers, Chicago, Milwaukee and St. Paul tracks and Dean boulevard, Minneapolis: (B 51), 50+ pounds of sand, screened through $\frac{1}{4}$-inch mesh screen, and (B 52), 75+ pounds of gravel, passed 2-inch screen. From yards of Minneapolis Brick and Tile Company, 4728 Lyndale avenue, Minneapolis, Minn.: (B 53), three sand-mold soft-mud brick, and (B 54), three wire-cut, stiff-mud brick. From yard of Menomonie Hydraulic Pressed Brick Company, Menominee, Wis.: (B 55), three sand-mold, medium to dark-red veneer brick. From the yard of the same company at Coon Creek, Minn.: (B 56), three wire-cut brick.

In addition to these samples, which have not yet been tested, the Survey has made tests on the crushed blue limestone from the quarry and plant of the Blue Limestone Company, at Fifteenth avenue NE., between Central and Fillmore streets.

STRUCTURAL MATERIALS AVAILABLE IN THE VICINITY OF AUSTIN, TEXAS.

By Ernest F. Burchard.

INTRODUCTION.

Central Texas, within a radius of 75 miles of Austin, is abundantly supplied with almost every variety of mineral structural materials, and this subject has already received attention from a number of investigators. When plans for the state capitol were being formed, a number of building stones were tested by Col. D. W. Flagler at the Rock Island arsenal, October, 1881, and the results were published in the report of the Texas Capitol Building Commission. Mr. E. T. Dumble, formerly state geologist of Texas, was one of the first to call attention to the building stones of Texas, through the medium of the state reports and the technical press.[a] Recently Dr. W. B. Phillips, director of the bureau of economic geology, University of Texas, has begun field and laboratory investigations of the building and ornamental stones of Texas[b] and has arranged in the museum of economic geology at the University of Texas, at Austin, a handsome and instructive exhibit of the most valuable materials.

Mr. Sidney Paige, of the United States Geological Survey, who has been studying the granites in Llano and Burnet counties, Tex., has contributed notes for this report on the granites of that area.

Prof. Alexander Deussen, of the department of economic geology, University of Texas, has cooperated with the writer in the collection of samples of cement materials, whose analyses are given on pages 314–316. The writer desires to acknowledge, with thanks, the assistance of the above-mentioned gentlemen in the preparation of this paper.

The country rock in the immediate vicinity of Austin consists mainly of Cretaceous limestone, shale, and clay. To the east lie younger deposits of sandstone, clay, and lignite of Tertiary age, and to the west and northwest lie older Paleozoic sedimentary rocks, surrounding a central core of ancient crystalline rocks, including large areas of granite. Colorado River cuts through the area from north-

[a] Dumble, E. T., Building stones of Texas: Stone, vol. 5, 1892, pp. 566–570.

[b] Phillips, W. B., Tests on Texas building stones: Min. World, June 24, 1905, pp. 654–657.

west to southeast, and within its immediate valley are Quaternary terrace deposits of clay, and river gravels and sands of more recent deposition. Among the materials of value yielded by the deposits mentioned above are red and gray granite for building and monumental purposes from Burnet and Llano counties; hard and soft white limestone for dimension stone, trimming, and rubble; limestone, clay, and shale for the manufacture of cement; limestone for quick lime, hydrated lime, and crushed stone; sand and gravel for concrete; sand for mortar and plaster. The terrace clays along Colorado River at Austin are used in the manufacture of common and face brick, and from the fire clays in the Tertiary at Elgin, Tex., are produced gray and buff dry-pressed face brick of a handsome type. The limestone and clay are not at present utilized for the manufacture of Portland cement; consequently supplies of this material are shipped in from Dallas and San Antonio, both located on the outcrop of the Austin chalk and adjacent clay, which also underlie Austin.

In view of the possibility of Portland cement being manufactured near Austin, some data are given as to the composition and character of the raw materials in this vicinity essential for Portland cement manufacture. The one important material which does not occur in the immediate vicinity of Austin, but which does occur in great abundance in north Texas, is gypsum, and plasters made from this material are comparatively cheap in the Austin market.

STONE.

LIMESTONE.

GENERAL STATEMENT.

In the immediate vicinity of Austin there are several limestone formations belonging to the Cretaceous system that contain beds suitable for building stone. The lowest formation, stratigraphically, is the Glen Rose limestone. Above this formation, and separated from it by formations of clay and chalky limestone, is another extensive formation known as the Edwards limestone. Overlying the Edwards limestone are the Georgetown and Buda limestones, which are separated from each other by a bed of clay, the Del Rio clay. All these limestones belong to the Lower Cretaceous. In the Upper Cretaceous there is one extensive formation, the Austin chalk, which has yielded stone for building purposes. The character of the most important of the formations just mentioned is described below.[a]

[a] For detailed descriptions, geologic maps, and sections of these formations, the reader is referred to the Austin folio (No. 76) of the Geologic Atlas of the United States, by Robert T. Hill and T. Wayland Vaughan. It may be obtained from the Director, U. S. Geological Survey, Washington, D. C., for 25 cents.

GLEN ROSE LIMESTONE.

The Glen Rose limestone underlies the plateau country northwest of Austin and forms the canyon of Colorado River, beginning about one-half mile above the city dam site and extending up the river for about 20 miles. It is well exposed in the river bluffs of Mount Bonnel and Mount Barker, in the canyons of Dry Creek and Bull Creek, and on the ridge between these creeks. The total thickness of the formation is about 450 feet. It consists principally of alternating hard and soft limestone beds of varying texture. Many of the beds are chalky and some are argillaceous. Occasionally a sandy phase of the rock may be noted, and in few places shaly layers are present. The hard beds are generally compact, but ledges of coarse, honeycombed stone have been noted. The rock is mostly cream-colored, with some white and gray layers and here and there a yellowish layer. The thickness of the individual beds ranges from a few inches to about 10 feet, or more. Many of the beds are fossiliferous and some of the fossils are large and abundant. Some of the beds are slightly oolitic. There appears to be a small proportion of iron oxide and magnesia disseminated throughout the formation, as is indicated by the light-buff or yellow color to which certain of the beds weather on exposure.

About 7 miles by wagon road northwest of the post-office at Austin there are some small quarries in the Glen Rose limestone. Walker's quarry (fig. 23, F) is situated on the hillside, southeast of the creek, and consists of two or three openings in light cream-colored limestone. The highest opening is in a fairly hard, even-grained, fine-textured, slightly oolitic limestone. The rock contains many small fossils, most of which are in a fragmental state. When fresh this stone shows small buff to yellowish specks of iron oxide, which give the stone, in mass, a light-buff tint; but this tint becomes lighter after the stone is thoroughly dry. The rock is horizontally bedded and the best ledge ranges from 10 to 14 inches in thickness. The joints are not numerous in the rock and slabs 3 to 5 feet in length and width may be obtained. Stone from this particular ledge possesses the hardness requisite to receive and hold a tool finish, and it is unfortunate that the ledge is not thicker. In the opinion of local stone masons, however, it is not necessary to lay this stone on its bed, and of course if it can be successfully laid on its edge stones cut from it can be faced in large dimensions. This ledge has been quarried for several hundred feet along the outcrop, where little or no cover had to be removed, and by the removal of a thickness of 2 or 3 feet of thin-bedded stone, débris, etc., an important supply of this stone might be uncovered. Between 60 and 100 feet lower down on the same hillside are softer beds of a finer texture and somewhat lighter color, which have been quarried to a larger extent. The softer stone is more easily worked and may be sawed by hand. It is capable of being tooled in the same manner as the harder stone but probably will not prove as durable. The Walker quarries are not being operated at present, but sufficient work has been done to demonstrate that a large supply of stone is available there.

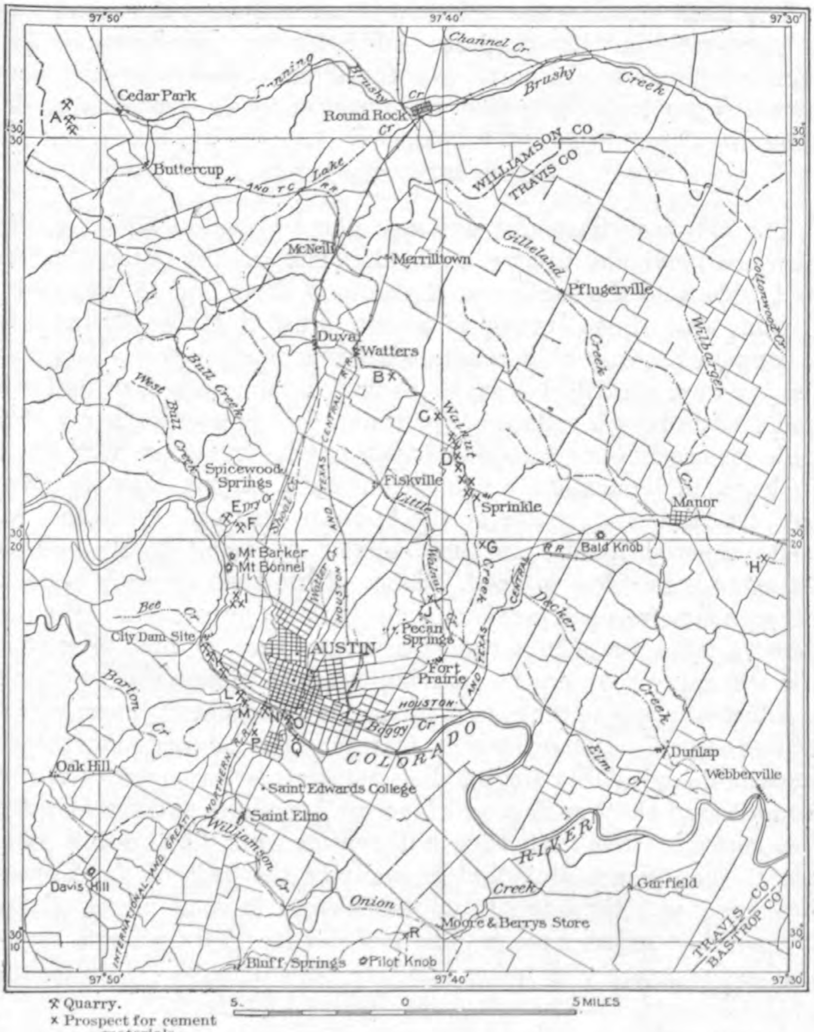


FIGURE 23.—Map of vicinity of Austin, Tex., showing location of stone quarries, gravel pits, brickyards, and prospects sampled for cement materials. From Austin and Georgetown topographic sheets, United States Geological Survey.

Across Dry Creek valley are quarries operated by Patrick Kelly (fig. 23, E), in rocks of the same horizon as those opened at the Walker quarry. The hard ledge at the top barely exceeds a thickness of 10 inches here. The lower ledge of softer rock ranges from 18 to 22 inches in thickness, but it is overlain by 15 inches of cherty limestone, which must be removed in order to get the material suitable for building stone. The principal drawback to working these stones on a large scale has been the distance that they must be hauled to the railroad or to the city. The road passing north of Mount Bonnel is well kept but has a steep grade close to Dry Creek.

The Kelly quarries are operated in a small way, the softer stone being used for building purposes and the harder stone for curbing and monument bases. In small lots the stone costs, at present, about 25 cents per running foot, or 50 cents per cubic foot delivered in Austin.

EDWARDS LIMESTONE.

The Edwards limestone outcrops along Colorado River, a short distance above and below the city dam site, and its outcrop extends and widens to the southwest of Colorado River and to the north of Austin, west of the International and Great Northern Railway. It is composed mostly of limestone, with some marly layers. In general the beds are whitish, but layers of buff, cream, yellow, or dull gray, and even brownish yellow, are present. In composition many of the beds are nearly pure carbonate of lime. The limestones vary greatly in degree of induration, ranging from hard, ringing, durable rock to soft, friable chalk. Some of the beds are coarsely crystalline, with well-preserved fossils, and are capable of being highly polished. Other beds are close grained. Some of the beds are very compact; others are porous and pervious. For building purposes only the compact varieties are of importance, and since there is some variation in the texture of the same bed it is important in prospecting to open up a sufficient space to prove that the bed is homogeneous in texture for some distance. One deleterious feature of the Edwards limestone as regards its suitability for building purposes is the presence of great quantities of chert or flint, which occurs in nodules and sheets of thin, flat lenses. These flints vary in dimension from 2 inches to a foot or more. Fossils are abundant in many of the beds of the Edwards limestone, and these fossils are detrimental in some places where it is desired to secure a stone to be tool faced. If the stone is used as rubble the presence of fossils is not so objectionable. The thickness of the Edwards limestone is probably about 300 feet.

On the northeast side of Colorado River 2 to 3 miles west of the post-office at Austin (fig. 23, K) are several old abandoned quarries in very hard limestone, which is considered to belong in the upper part of the Edwards limestone. One bed in this vicinity is composed of a mass of large fossil shells, which have been almost entirely replaced by calcite. This stone has a white chalky color on fresh fracture, and in places it is tinted cream-yellow and pale pink. It is susceptible of high polish and when polished makes a beautiful stone for interior purposes; on this account it has been called the "Austin marble." It is not at present commercially utilized for decorative purposes but has been largely used as rubble, as may be seen in the facing of the foundation of the present federal building at Austin. Close to these fossiliferous beds are beds of hard light-gray fine-grained limestone, containing only a few fossils. The stone contains numerous crystals of calcite scattered here and there through the mass, and occasionally a slight stain of iron oxide may be noted. The bed most suitable for cut-stone work is about 14 inches thick, and there are a number of other beds from 6 inches to 1 foot in thickness. Stone of this character from the Banker quarry was used in the facing of the present post-office building above the foundations. The rock was tool faced and has withstood the thirty years' exposure to the weather exceedingly well. In January, 1910, the stone appeared to be almost white in color, but it is understood that the building has been cleaned by rubbing two or three times since it was completed, the last cleaning having been done within the past three years. At the Johnson quarry there is a small quantity of stone of this character available which needs no stripping, but in order to obtain a supply of stone sufficient for the new federal building it would probably be necessary to strip one-half acre of stone averaging 6 feet thick, which lies above this homogeneous bed. About a mile west of the Johnson quarry, or three-fourths of a mile below the dam site, is an abandoned quarry in very hard, coarsely crystallized gray limestone, which occurs in massive beds 2 feet or more thick. Little of this stone is available without considerable stripping, but the stone is very durable and of a pleasing color and texture.

At Oak Hill, about 7 miles southwest of Austin (see fig. 23), there occurs a very hard limestone, either in the basal part of the Edwards limestone or in the upper part of the Glen Rose limestone, that is reported to have been used in the foundations of the capitol at Austin.

The most extensive working quarries of building limestone in the vicinity of Austin are at Cedar Park, on the Houston and Texas Central Railroad, about 27 miles northwest of Austin. This rock, which is here provisionally referred to the Edwards limestone, outcrops, or lies below only a few inches of soil, over a large area of the divide between Colorado and San Gabriel rivers, west of the Houston and Texas Central Railroad. It is quarried at three places, west and northwest of the station of Cedar Park (fig. 23, A), and is hauled to the railroad at Cedar Park and to Leander. The rock that is quarried consists almost entirely of calcium carbonate and is soft enough when freshly quarried to be cut with a handsaw. When fresh and containing quarry moisture, the rock is decidedly cream-colored. When removed from the quarry it soon dries to light gray or nearly to white. After weathering it becomes of a light-cream to light-buff color. The rock is compact, fine grained to subcrystalline, and in places slightly oolitic. The beds are massive and show no stratification within 6 or 7 feet of the surface, the maximum depth to which the rock has been opened by working. The rock that is quarried is slightly fossiliferous, and it is reported that below the portion that is quarried fossils are so numerous as to render the stone less desirable. The rock has a metallic bell-like ring in large blocks, especially when dry. It is reported to weigh 150 pounds per cubic foot and to withstand a crushing strength of about 2,960 pounds per square inch. Relatively, therefore, this rock is not very hard or strong, but it appears suitable for building purposes in the dry climate of central and southwest Texas, where it has been used probably more than any other of the local stones, both for facing and for sills, caps, water tables, columns, and other exterior trimmings. The two quarries nearest to Cedar Park are operated by Cluck & Richards and E. Cluck & Bro. The stone is stripped by scrapers and by hand and is quarried by channeling to depths of 5 to 7 feet, boring under the blocks by hand augers, and then wedging them up. The quarries of the above-mentioned firms consist of irregularly shaped pits about 300 feet long. The rock is handled by derricks and hauled by wagon to the railroad in mill blocks. The only limitation to the size of blocks obtainable lies in the facilities for lifting and transporting the stone. The stone is so easily cut and dressed on the job that the quarrymen do not attempt to produce dimension stone. The present prices on the stone are, in mill blocks, 20 to 25 cents per cubic foot, f. o. b. Cedar Park. The combined output of these quarries is more than 50,000 cubic feet of stone annually, and the supply of stone that is available under present conditions is very great, because the above companies control 400 acres of stone land. It is reported that the stone at Cedar Park has been used in federal buildings at Gainesville and Laredo, Tex.

AUSTIN CHALK.

The Austin chalk occupies a northeast-southwest belt, from 2 to 5 miles wide, within which is the city of Austin. This formation has been traced from a point north of Dallas to one southwest of San Antonio and is very similar in character throughout its extent. The rock is a white chalky limestone of fine to coarse texture and occurs in beds of varying thickness, separated in places by friable beds of marl. When fresh and impregnated with ground water the chalk has a bluish tint, but it usually bleaches white when dry and in places shows slight blotches of yellow from the oxidation of specks of iron pyrite. Fossils are abundant in places in the Austin chalk and range from the shells of Foraminifera and other minute organisms to large *Inoceramus*, oyster shells, and ammonites. The Austin chalk may be some 500 feet thick, and for the most part its beds are very poorly indurated. In all localities noted the hardest beds were softer than the stone at Cedar Park described above. One sample of stone, which is very fine grained, homogeneous, of a light cream color, and susceptible of a smooth rubbed finish, was produced from the property of Fisher & Bro., about 7 miles southwest of Austin, about one-fourth mile from the International and Great Northern Railroad. It is reported that this stone can be delivered in Austin for about 30 cents a cubic foot.

GRANITE.

INTRODUCTORY STATEMENT.

Within the past two years the United States Geological Survey has been making a geologic map of the Burnet and Llano quadrangles, northwest of Austin. Mr. Sidney Paige, one of the geologists engaged on this work, has mapped the granites in the field and has made detailed studies of them in thin sections under the microscope. The following notes on granite are contributed by Mr. Paige.

GENERAL OCCURRENCE.

Granite occurs in great abundance in the pre-Cambrian complex of Llano and Burnet counties, Tex. Many large areas exist where pure, clean stone can be found. Many areas exist also where the granites are mixed with fragments of the schists which they have intruded. The opening of quarries in areas characterized by this latter condition is always a more or less hazardous undertaking, for though an area may be selected which seems quite sufficient to form a workable quarry floor, no assurance can be had that the rock will continue clean in depth. A number of such quarries have been opened in Llano County, and the experience of quarrymen has shown that much care must be exercised to avoid such mixed zones. The desire to obtain a stone easily worked has been one of the factors leading to the selection of such localities, for clean rock in areas where it was very little altered has been reported to be too hard to be desirable by the monument workers. Why the stone should be softer in these mixed areas is not known.

Though there are present in this region many varieties of stone, a rough classification may be made into (1) a coarse-grained pink variety, (2) a fine to medium grained gray variety, and (3) a fine to medium grained pink variety.

The first has been most extensively quarried at Granite Mountain, Burnet County. In Llano County Teich's quarry No. 2 has produced stone of this character.

Of the fine to medium grained varieties the gray is far more abundant. In many places granite that is pink on the surface will prove gray in depth. There do exist, however, in this region pink granites of fine to medium grain.

The coarse-grained granite of southwestern Llano County will probably some day be utilized. There is an almost unlimited quantity of this stone.

Facilities for shipment undoubtedly vitally affect the Llano County granite industry. With increasing growth of the large cities in the South and with additional railroads there should be established a more profitable and extensive industry than exists at present. Though now the larger part of the rock is used for monumental purposes, there is much granite eminently suited for large structures if means of shipment were better and a more active market available. Until such a condition exists it is doubtful if any considerable growth of the industry will take place. The construction of the Galveston jetty has provided one of the largest markets for rough and crushed stone.

GRANITE MOUNTAIN QUARRY.

The Granite Mountain quarry is located on the Houston and Texas Central Railroad at Granite Mountain, Burnet County, near the town of Marble Falls. The owners since 1893 are Darragh & Catterson. Before that date the property was owned by Lacey, Westfall & Norton.

The quarry is opened in the side of a broad, low, bare granite hill. No stripping is necessary. Sufficient granite is exposed above the present railroad grade to furnish material for a great many years.

The rock is a coarse-grained pink granite, consisting of quartz, microcline (dominant), albite oligoclase and some orthoclase feldspars, and biotite mica. Though portions of the mass are intruded by pegmatite, an enormous quantity of fine material is at hand. A well-defined rift aids quarrying. Sheets of any desirable thickness can be lifted, and handling sets the only limit to the size of blocks that may be obtained. The greater part of the rock quarried has been shipped in 5 to 10 ton blocks and as crushed stone to the Galveston sea wall. This work was begun in 1891 and continued to 1898. Little work was done from 1898 to 1902. From 1902 to the present time about 1,000,000 tons of rock was shipped. Before that, however, 2,000,000 tons was shipped, and in addition 120,000 yards of crushed rock has been used on the same work. Probably 2,000,000 tons was used as cap rock.

The capitol building at Austin, begun in 1884 and finished in 1899, and court-houses in Galveston, Houston, and other localities are built of this granite. Nevertheless, but a small part of the output has been dimension stone. This class of work will probably grow in importance.

The quarry is equipped with 20-ton rigging. There are five derricks, a 1,500-foot cableway, and a tram. The rock is generally swung direct to the cars. A No. 7½ Gates crusher is also installed. Engineers are paid $2.50 to $3.50; derrickmen, $2.75 to $3; foremen, $4; common laborers, $1.50 to $1.75.

Freight rates per ton on rough granite.

Granite Mountain to Galveston	$1.25
Granite Mountain to Houston	1.15
Granite Mountain to Aransas Pass	1.40
Granite Mountain to Sabine Pass	1.35
Granite Mountain to San Antonio	1.00
Granite Mountain to Fort Worth and Dallas	1.30

TEICH QUARRY NO. 2.

This quarry is a short distance west of Kingsland, Llano County, and is connected by a spur with the Houston and Texas Central Railroad. It is owned by Frank Teich, of Llano, and was opened in 1908. The rock is a coarse-grained pink granite and takes a fine polish. The Memorial Church of Orange, Tex., is built of this rock. About 50,000 cubic feet have been quarried, valued at 50 cents a cubic foot. The quarry was not being worked when it was visited.

Mr. Teich operated a small quarry on the Parkinson tract 6 miles south of Llano during the summer of 1909. About 6,000 cubic feet was extracted and manufactured into monuments at Teich's polishing works near Llano. This quarry was abandoned the past summer. A new quarry, Teich No. 3, is being opened about 4 miles south of Llano.

GOOTCH & WELLS QUARRY.

Gootch & Wells are operating a quarry on the Parkinson tract about 6 miles south of Llano, Llano County. The quarry presents a very rough and irregular appearance. The pit is from 25 to 50 feet deep and about 150 feet long in an east-west direction. It is about 100 feet wide at the east end, but narrows to 15 or 20 feet at the west end. The rock lies in somewhat irregular sheets broken by vertical joints. N. 50° E. is the easiest break.

The following section will give an idea of the sheeting:

Section showing sheeting in Gootch & Wells quarry, Llano County, Tex.

	Feet.
Top ledge, not used (low dip northwest)	5–10
Rotten granite	1– 2
Thick ledge	12±
Rotten seam	½
Ledge	8
Ledge	4

The thickness of the sheets varies considerably and the presence in parts of the quarry of pegmatite and schist inclusions spoils much rock. The stone is a beautiful gray granite, somewhat resembling the stone of Barre, Vt. It consists of quartz and microcline feldspar, with a little albite oligoclase and orthoclase feldspar. Biotite in small flakes is the dark mineral. The quarry is equipped with four derricks, a gasoline engine, and five air drills. Plug and feathers are largely used for breaking on the finish work. If pushed, the quarry could produce 250 cubic feet per day.

The granite is hauled to the Houston and Texas Central Railroad at Llano by wagons at a cost of 15 cents a cubic foot. Freight on rough stock varies from 50 cents to $2.50 a ton in the State. From Llano to Houston the rate is $1.45. The entire product of the quarries is used for monumental work. The actual cost of quarrying is about 40 cents a cubic foot, varying with the nature of the seams in the quarry. The rough stone is sold from the quarry. Dressing costs from $1 to $25 a cubic foot, depending on the designs. The best quality of stock sells for $1.50 a cubic foot, this grade being used for the best polished work. The cheapest stock, used for hammered work, sells for 90 cents a cubic foot.

The quarry produced during 1908 about 18,000 cubic feet and will produce during 1909 about 22,000 feet. The entire Parkinson tract produced during 1908 (including quarries operated by George Patterson, T. A. Blodgett, Mr. Seiter, and Frank Teich) about 33,000 cubic feet.

NORTON QUARRY.

The Norton quarry, owned by Mrs. Norton, of Llano, is about 11½ miles southwest of Llano and about 3½ miles a little east of south of Sixmile post-office. The quarry pit is nearly rectangular, and measures 95 feet long in a north and south direction. It is about 55 feet wide and 12 to 15 feet deep. Natural walls caused by small north and south seams make the west and east sides. The north end, trending N. 60° E., is a very straight break. The rock breaks easiest the "capping way," while north-south and east-west breaks are about the same in this respect. The stone is a bluish-gray fine-grained granite composed of quartz and microcline feldspar essentially, with a little albite oligoclase and orthoclase. The dark mineral is biotite mica in fine flakes. A little chlorite is present. Pyrite was noted, occupying almost invisible seams. It is not abundant, however, though some fine blocks are spoiled by its presence. Schist fragments also spoil some of the other rock. The plant consists of two derricks and a horse winze.

E. L. STEWART QUARRY.

Mr. E. L. Stewart, in August, 1908, opened a new quarry near the old Stewart quarry, about 10½ miles southwest of Llano and about 2½ miles a little west of south of Sixmile post-office.

The rock is a fine-grained gray granite. Pyrite is very abundant in parts of the old Stewart quarry near by and may also interfere with the new opening. Schistose material is included in much of the granite of the vicinity, and this fact, combined with the presence of pyrite and the long haul to the railroad, will probably prevent extensive developments. Two carloads have been shipped to San Antonio and Paris markets, principally for monumental purposes. The rock is hauled for 25 cents a cubic foot loaded at the quarry and unloaded at Llano. Quarrymen receive from $2 to $2.50 a day.

BRADSHAW QUARRY.

Mr. Bradshaw has opened a small quarry one-fourth mile west of the Gootch & Wells quarry. Only the top rock has been removed over a small area.

H. P. BAILEY QUARRY.

Mr. H. P. Bailey is also opening up a quarry three-fourths of a mile north of Bradshaw's. Only a few cubic feet of rock has been quarried.

OTHER LOCALITIES.

Mr. George Patterson is operating a quarry on the Parkinson tract south of Llano, but no notes are at hand covering the work.

A number of quarries have been worked in the past, but for the present at least are abandoned. Such are the Town Park quarry north of Llano, where pyrite marred a very beautiful coarse-grained gray granite porphyry; the Kansas City quarry, 2 miles west of Llano on the Mason road; and the quarry 7 miles northwest of Burnet, where a very dark gray, slightly gneissoid granite has been quarried.

RESULTS OF TESTS.

The following table, showing the results of tests of compressive strength and other physical properties, permits a direct comparison of the various Texas building stones.

Results of tests of Texas building stones.[a]

No.	Material.	Location.	Dimensions.			Compressive strength.			Percentage of absorption.	Specific gravity.	Weight per cubic foot.
			Height.	Cross section.	Area of cross section.	Pressure at which it cracked and spalled.	Pressure at which it crushed.	Crushing strength per square inch.			
			Inches.	*Inches.*	*Sq. in.*	*Pounds.*	*Pounds.*	*Pounds.*			*Pounds.*
1	Limestone	Austin (court-house stone)	4	2.25 by 2.25	5.027	17,200	17,200	3,422	0.068	2.1616	134.76
2	Do	Duval, Gault quarry	4	2.20 by 2.25	4.95	28,300	31,200	6,303	.031	2.3915	149.09
3	Do	8 miles from Austin, Hancock quarry	4	2.37 by 2.37	5.617	12,000	12,800	2,279	.058	2.1794	135.86
4	Limestone (fossil)	Austin, Loomis & Christian quarry	4	2.28 by 2.25	5.13	22,300	42,100	8,207	.011	2.5992	162.03
5	Limestone	Burnet County, Honey Creek	4	2 by 2	4	35,000	59,800	14,950	.0004	2.7057	168.67
6	Do	12 miles south of Austin, Slaughter Creek	4	2 by 2	4	....	80,115	20,029	.0623	2.25	....
7	Do	....do	4	2 by 2	4	....	58,180	14,545	.0597	2.278	....
8	Do	....do	4	2 by 2	4	....	79,000	19,750	.0655	2.251	....
9	Do	....do	4	2 by 2	4	....	81,280	20,320	.0092	2.588	....
10	Do	13 miles south of Austin, Bear Creek	4	2 by 2	4	....	29,365	7,341	.0899	2.119	....
11	Do	....do	4	2 by 2	4	....	49,020	12,255	.0845	2.153	....
12	Do	....do	4	2 by 2	4	....	40,040	10,010	.0554	2.265	....
13	Do	....do	4	2 by 2	4	....	29,220	7,305	.0589	2.248	....
14	Do	Cedar Park	1	1 by 1	1	2,300	2,300	2,300	.1021	3.47	157.87
15	Do	Round Rock	1	1 by 1	1	1,495	1,495	1,495	.1205	3.26	144.77
16	Do	McLennan County	1	1 by 1	1	3,180	3,180	3,180	.0573	2.97	158.49
17	Do	Lueders, Jones County	1	1 by 1	1	2,487	2,487	2,487	.0474	2.91	160.37
18	Marble	Burnet County, Fort Croghan quarry	4	2.27 by 2.24	5.0848	69,290	70,080	13,782	.0039	2.679	166.99
19	Marble (pink)	San Saba County	1	1 by 1	1	5,100	10,330	10,330	.0062	2.81	166.7
20	Marble (black)	Brewster County, Jordan quarry	1	1 by 1	1	....	10,420	10,420	.0016	2.74	170.35
21	Marble (white)	....do	1	1 by 1	1	....	3,784	3,784	.0021	2.10	130.41
22	Sandstone	Fairland, Burnet County	1	1 by 1	1	2,800	4,450	4,450	.0601	2.91	154.75
23	Sandstone (gray)	Moulton, Lavaca County	1	1 by 1	1	2,100	2,400	2,400	.0941	2.81	149.76
24	Sandstone (red)	Ward County	1	1 by 1	1	1,900	2,000	2,000	.0738	3.04	156
25	Granite (red)	Burnet County	4	2 by 2.11	4.22	49,900	50,180	11,891	.0009	2.625	163.64
26	Do	Llano County, Teich quarry	1	1 by 1	1	9,600	11,990	11,990	.0028	2.64	163.49
27	Granite (gray)	....do	1	1 by 1	1	10,900	11,950	11,950	.0028	2.69	165.98
28	Do	Llano County, Bradshaw quarry	1	1 by 1	1	7,970	10,060	10,060	.0021	2.70	167.23
29	Granite (light-gray)	Burnet County, Ueberali quarry	1	1 by 1	1	8,310	9,340	9,340	.0021	2.76	170.97
30	Granite (dark-gray)	....do	1	1 by 1	1	10,650	10,880	10,880	.0021	2.95	182.83
31	Granite ("opal")	Llano County	1	1 by 1	1	11,800	15,300	15,300	.0036	2.67	164.73
32	Granite	Presidio County	1	1 by 1	1	7,220	15,970	15,970	.0073	2.67	163.49
33	Serpentine	Gillespie County, 35 miles south of Llano	1	1 by 1	1	8,400	8,950	8,950	.0079	2.61	159.74

[a] Nos. 1 to 13, 18, and 25 were tested by Col. D. W. Flagler at Rock Island Arsenal, October, 1881, and the data published in the report of the Texas Capitol Building Commissioners, 1883. Nos. 14 to 17, 19 to 24, and 26 to 33 were tested at the engineering department, University of Texas, and the data published by Dr. W. B. Phillips, of the University of Texas, in the Mining World, June 24, 1905.

MATERIALS FOR CONCRETE.

SAND.

The supplies of sand used in Austin and vicinity are derived from the bars along Colorado River, above and below the new concrete bridge at the foot of Congress avenue. At low water there is a bar at least one-half mile long, 600 feet wide, and 3 to 5 feet deep above low-water level (fig. 23, O). The material in this bar consists of fine sand to coarse gravel and small bowlders. In places there are layers of silt and quicksand, but pockets of materials that have been washed thoroughly clean by the water are extensive, and sand of almost any degree of coarseness may be obtained. The sand is light pink and consists chiefly of quartz and pink feldspar grains, together with a small proportion of limestone, magnetite, and traces of white mica flakes. The sand grains are subangular, round, or angular and feel sharp and gritty. The sand usually leaves little or no clay stain on the hand. When it is treated with hydrochloric acid a brisk effervescence is noted, due to the presence of grains of limestone and fine shell fragments. A sieve test on a sample averaged from sands from two points on the bar showed results as follows: Passed through ¼-inch mesh, 100 per cent; remained on 20-mesh, 20 per cent; on 40-mesh, 55 per cent; passed through 40-mesh, 25 per cent.

The sand thus appears to be well graded and low in voids. The supply available at low water is inexhaustible at the present rate of excavation. It is hauled by teams from the river to any point in Austin and is shipped by carload lots to many points within a radius of 100 miles of the city. It is used for stone and brick mortar, concrete, and plaster. In small quantities it will cost about 75 cents a square yard delivered in Austin. The cost for large quantities delivered at the post-office site, which is not a long haul, should be considerably less.

GRAVEL.

Gravel may be obtained in abundance from the bar described above in connection with sand. The gravel occurs in places clean enough to be used without screening, but is mostly mixed with sand. The gravel consists mainly of rounded pebbles of limestone, quartz, chert, jasper, and of granitic rocks from the crystalline area in Llano and Burnet counties, from which the material has been transported by the river. The gravel of Colorado River is used together with sand very generally for concrete walks in Austin and to some extent for building purposes. A noteworthy example of the use of this gravel and sand in concrete is the new concrete bridge across Colorado River at the foot of Congress avenue. This bridge has just been completed of poured concrete. The sand and gravel were obtained from the bar just above the bridge. The sand was screened out of the gravel, washed down a chute, then remixed with the gravel in definite proportions to form the aggregate.

CRUSHED STONE.

Crushed limestone is delivered to the Austin market from the quarries of the Dittlinger Lime Company, near New Braunfels, about 50 miles south-southwest of Austin on the International and Great Northern Railroad. The crushed stone produced at this place is cream-colored to light yellowish and appears to be well graded and fairly well screened but contains some dust. One good feature of the stone is the approximately cubical shape taken by the crushed fragments. The Dittlinger Company operates a No. 5 Simons crusher, with a rotary screen, making four separations, as follows: Screenings below $\frac{5}{16}$ inch; stone between $\frac{5}{16}$ inch and 1 inch, between 1 inch and $1\frac{5}{8}$ inches, and between $1\frac{5}{8}$ inches and $2\frac{1}{2}$ inches.

The capacity of the plant is about 150 cubic yards a day, and the cost of the material, f. o. b. Austin, ranges from $1.30 to $1.55 a short ton.

CEMENT.

No Portland cement is at present manufactured at Austin, although, as will be shown below, there are raw materials here in abundance for such manufacture. The principal supplies of cement are shipped from Dallas, and the present prices are quoted at about $2 a barrel, delivered, not including the price of sacks.

BRICK.

GENERAL STATEMENT.

Two firms are manufacturing brick at Austin. Both obtain their clay from the low terrace on the south bank of Colorado River. (See fig. 23, N and L.) The Butler Brick Works are located on the south bank of the river, just west of the International and Great Northern Railroad tracks. The Austin Brick Company's brickyard is on the north bank of the river, about three-fourths of a mile west of the International and Great Northern Railroad bridge, and the supplies of clay are conveyed across the river from the pit to the brickyard on an aerial cableway. Both these yards manufacture a soft-mud, sand-mold common brick and a dry-pressed brick which is designed for use as a moderate-priced face brick.

COMMON BRICK.

The common brick made by both firms are cream-colored, fairly uniform brick, some of them showing a few lime specks and spalls. The brick are burned in permanent-wall, side-fired, updraft kilns, using Rockdale (Tex.) lignite as fuel. The brick show a good sharp break and are not very hard. They are easily overburned, as they tend to fuse at a comparatively low temperature. When underburned the brick are mottled pink in color, so that soft brick are easily detected. The capacity of each plant is about 30,000 sand-mold brick per day, and the stock ranges from 100,000 to 1,000,000 brick, which are stored in the kiln sheds. Present prices on the common brick, delivered in Austin, range from $7.50 to $8 per thousand.

FACE BRICK.

The face brick made by each firm are of a dry-pressed, bright cream-yellow variety, show good sharp edges and a sharp break, but are not very hard. The porosity of these brick appears to be relatively high, and the fusing point at which the clay was burned is relatively low, owing to the high percentage of calcium carbonate in the clay. (See analyses Cy 30 and Cy 31, page 315.) These dry-pressed brick are burned in downdraft kilns with Rockdale lignite as fuel. From 20,000 to 30,000 brick a day are made by each plant. Stocks of 100,000 to 500,000 brick are carried in the kilns. The cost of these brick, delivered in Austin, at present is $13 to $15 a thousand.

Tests on soft-mud brick from Butler's brickyard, made at the engineering department of the University of Texas, showed crushing strengths per square inch ranging from 2,855 to 3,434 pounds, and on dry-pressed brick they ranged from 3,797 to 4,801 pounds. Absorption of the soft-mud brick ranged from 18.1 to 20.74 per cent and of the dry-pressed brick from 19.5 to 21.4 per cent. The crushing tests were made on one-half bricks.

The Butler Company operates at Elgin, Tex., 27 miles east-southeast of Austin, on the Houston and Texas Central Railroad, a brickyard known as the Elgin-Butler Brick and Tile Company's, at which face brick and fire brick are made. The face brick range from light gray to buff in color and are embellished with manganese specks in varying quantities. The brick are made by the dry-press process from fire clay, which is first crushed in a dry pan and screened. Oil is used as fuel, and the kilns in which the brick are burned are of the downdraft pattern. These brick are uniform in size and are shaded in five or six different colors. About 40,000 brick a day are reported to be made at this plant, and a stock of some few hundred thousand brick is carried under sheds. The present price of these brick is about $24 per thousand, f. o. b. Austin. Shade No. 415, a light-gray brick, finely specked with manganese, is said to have been used in the federal building at Houston, Tex.

Tests made by A. C. Scott at the University of Texas in 1909 on one-half bricks from the Elgin-Butler Brick Company showed results as follows:

Tests on face brick from Elgin-Butler Brick Company, Elgin, Tex.

Brick No. 425, surface, 17.27 square inches:
  Failure started at 78,000 pounds, or 4,516 pounds per square inch.
  Failure was total at 90,600 pounds, or 5,246 pounds per square inch.
Brick No. 450, surface, 17.27 square inches:
  Failure started at 77,600 pounds, or 4,493 pounds per square inch.
  Failure was total at 100,000 pounds, or 5,790 pounds per square inch.

MATERIALS FOR MORTAR AND PLASTER.

Sand.—The sand of Colorado River described above is used for all classes of mortar and plastering work. It is generally necessary to screen the sand in order to secure a sufficiently fine-grained material for these purposes.

Lime.—Lime is manufactured at three places in the vicinity of Austin, namely, at McNeil (fig. 23), by the Austin White Lime Company; at Round Rock (fig. 23), by the Round Rock White Lime Company; and at New Braunfels, by the Dittlinger Lime Company. All these companies manufacture from high-calcium Cretaceous limestone, and both hydrated lime and quicklime are produced by the three firms. These products cost in Austin about 80 cents per 200-pound barrel.

Plaster.—Gypsum wall plasters manufactured in northern Texas are used at Austin. The Acme Cement Plaster Company puts the following products on the market: Cement plaster (brown coat), at $9 a ton, delivered; white plaster (stucco or plaster of Paris), at $10.50 a ton; Keene's cement, at $19.50 a ton.

The Agatite brands of plaster, manufactured by the American Cement Plaster Company, consist of the same varieties (except Keene's cement, which the company does not manufacture) and retail at the same prices.

SAMPLES.

Samples as follows have been sent for test to the Survey laboratory at Pittsburg, Pa.: B 79, sand from Colorado River, below wagon bridge, Austin, Tex.; B 80, sand and fine gravel; B 81, sand and coarser gravel; B 82, gravel. All these samples are from the same bar in Colorado River and consist of about 50 pounds each.

NOTES ON PORTLAND CEMENT MAKING MATERIALS.

GENERAL STATEMENT.

The results of a number of chemical analyses of limestone, clay, etc., from the vicinity of Austin, Tex., are given below. They were made at the laboratories of the United States Geological Survey in St. Louis in 1908, on representative samples of material ranging generally from 20 to 50 pounds in weight, and are part of a series of tests that were planned for the promising deposits of undeveloped cement-making materials of the United States. Along with these analyses it was planned to make kiln tests on the raw materials and certain experiments with various fuels, including lignite and producer gas, to grind the clinker, and to make the usual physical tests on the resulting cement, but lack of the necessary funds prevented a continuation of this work in 1909.

CHARACTER OF THE ROCKS.

Beginning with the lowest formation the rocks here considered of possible value as cement materials are as follows: The Georgetown limestone and Del Rio clay, both of the Lower Cretaceous, and the Eagle Ford clay, Austin chalk, Taylor marl, and Webberville formation of the Upper Cretaceous. In the valley of Colorado River are terrace silts of Quaternary age. These silts overlie the Cretaceous unconformably. The formations strike northeast-southwest and dip at low angles to the southeast. The oldest rocks outcrop just west of Austin, the later ones overlapping from the east.

The Georgetown limestone consists of impure white limestone alternating with bands of marly clay. Its total thickness is 65 to 70 feet. The principal impurities are silica and alumina, which are not excessive, but there are some beds that carry too much magnesia. (See analysis Se 329, p. 314.) This limestone outcrops in low bluffs and on hill slopes in the vicinity of the old cement works northwest of Austin. (See fig. 23, I.)

The Del Rio consists of greenish-blue laminated unctuous clay which weathers brown or yellow. It is rather fossiliferous, containing many seams of calcareous shells, and in places these shells have reacted with ferrous sulphate and formed selenite crystals. This clay lies upon the Georgetown limestone. Its thickness is 80 to 100 feet, but the whole thickness rarely remains except where the clay is protected by the overlying Buda limestone. The outcrop areas of both the Georgetown and the Del Rio formations are narrow. As shown by the analyses (Cy 15 to Cy 25, p. 314), the Del Rio clay is generally rather low in silica as compared to the percentage of iron and alumina, and it also runs high in lime. The best sample of Del Rio clay appears to be Cy 32.

The Eagle Ford clay is composed of laminated bituminous clays, shales, and flaggy limestone. It outcrops in narrow areas northwest of a line drawn northeast-southwest through the middle of Austin. It is usually exposed in low bluffs below a cap of Austin chalk, which is the next higher formation. The total thickness of the Eagle Ford is about 50 feet in the vicinity of Austin. The composition, as shown by analyses Se 361, 364 and 365, approaches that of natural cement rock rather than that of true shale.

The Austin chalk is described on pages 298-299. Analyses Se 335 to 363 indicate that the chalk runs uniformly and moderately high in lime and low in magnesia. The silica is generally in moderate amounts, not too high for the corresponding percentages of alumina and iron oxide.

Overlying the Austin chalk and occupying an outcrop area 3 to 6 miles wide east of the chalk area is a thickness of more than 500 feet of calcareous joint clay or marl. When fresh these beds consist of fine-grained, tough, unctuous blue clay, which quickly becomes laminated and changes to yellow on weathering. This formation is known as the Taylor marl. The material, as shown by analyses Misc. 80 and 81, is neither a natural cement rock nor a good limestone, although it would not require the addition of a large proportion of limestone to bring it up to the composition of a cement mixture.

Next above the Taylor marl is the Webberville formation, which is composed of clay marls with greenish glauconite grains and of black shaly clay with arenaceous layers. Analyses of clay from the Webberville are shown as Cy 26, 27, and 28. This clay is not very uniform in composition, but in places some material fairly high in silica may be found, such as sample Cy 27.

The terrace silt from the south bank of Colorado River is used for making brick at two places. It is calcareous, although less so than most of the so-called shales and clays of the vicinity. Analyses Cy 30 and 31 show respectively a rich clay, used for making dry-pressed face brick, and a loamy clay, used for making soft-mud sand-mold brick.

GENERAL CONCLUSIONS.

Chemical analyses are no longer considered as entirely reliable indices of the true value of raw materials for Portland cement making. They do indicate, however, by comparison with analyses of materials of known value, whether the material in question is worth testing further. In the absence of complete kiln and physical tests, it is not safe to make definite assertions as to the quality of Portland cement that might be made from these materials. It is of interest to note, however, that at Dallas, Tex., good Portland cement is being made from the Austin chalk mixed with Eagle Ford clay, and that at San Antonio Austin chalk is also in use for natural and Portland cements. (See analyses, p. 316.) Austin, an intermediate point on the outcrop of these widespread formations, would thus appear to be favorably situated with respect to these important raw materials. Some years ago cement was made at Austin on a small scale in a vertical kiln from rocks stratigraphically lower than the Austin chalk, namely, the Georgetown limestone and the Del Rio clay. An analysis of seasoned clinker from this kiln (No. 4 of the following table) corresponds closely with the average of ten samples of a mixture of seven standard Portland cements. In 1904 analyses and clinkering tests of limestone and clay from the properties of the Austin Portland Cement Manufacturing Company were made at the laboratories of a large Portland cement company in the North. For purposes of comparison the following analyses are given:

Analyses of raw materials and manufactured cement from Austin, Tex.[a] *(fig. 23, I).*

	SiO_2.	Al_2O_3.	Fe_2O.	CaO.	MgO.	Loss by ignition.
1. Georgetown limestone	5.90	2.90	0.72	49.70	0.20	40.34
2. Del Rio clay	41.68	16.51	2.89	17.10	.20	19.14
3. Resulting cement	20.99	8.81	1.60	68.31	.20	....
4. Old cement clinker	21.44	8.52	3.15	59.44	.36	4.09
5. Typical cement mixture	22.01	6.78	3.21	62.74	2.64	....

[a] Nos. 1, 2, and 3 were made at the laboratory of a working Portland cement plant. Reported by owners of property.
Nos. 4 and 5 made at the laboratories of the U. S. Geol. Survey, St. Louis. Mo.

For the kiln test the limestone (1) and clay (2) were mixed in the proportion of about 3.9 to 1, ground wet to such fineness that practically all the mixture passed a 200-mesh sieve. The mix was dried and burned in a test kiln with gas fuel. The clinker was well sintered and dense and after being finely ground yielded a gray cement having good hardening properties. The results of some of the physical tests were as follows:

Results of physical tests on cement yielded by kiln test on mixed Georgetown limestone and Del Rio clay.

Time of set: Initial, three and one-half hours; final, seven hours.
Specific gravity: 3.12.
Fineness: Passed 100-mesh, 99 per cent; passed 200-mesh, 88 per cent.
Tensile strength, neat: Seven days, 655 to 805; twenty-eight days, 882; one year, 665 pounds per square inch.
Tensile strength, 1:3 sand: Seven days, 425 to 460; twenty-eight days, 471; one year, 375 pounds per square inch.

To be of value for the manufacture of Portland cement shales should contain silica in the proportion of not less than twice nor more than three times the alumina plus the iron oxide, and some manufacturers report best results when the ratio $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ is between 2.5 and 3.

Inspection of the analyses of all the clays and shales in the table on page 314 shows that in not one of the Del Rio clay samples does this ratio reach as high as 2.5, and in some samples the ratio is less than 2. Only one out of the 20 clays, namely, Cy 28, gives a ratio between 2.5 and 3, although Cy 27 and Cy 32 come close to 2.5. It is evident that these clays should be used in connection with limestones carrying enough silica to make up for the lack of it in the shale. Possibly the necessary silica might be supplied from certain of the more highly siliceous beds in the Georgetown limestone and the Austin chalk. It should be noted that analyses Se 328 and Se 329 show more than the maximum allowable limit of magnesia (MgO), which is generally considered to be 3 per cent. The Austin chalk runs generally higher in lime than the Georgetown limestone and is uniformly low in magnesia. The Eagle Ford clay, according to the analyses, appears to be nearly a natural cement rock, which would require the addition of only a small proportion of high-calcium limestone to make a Portland cement mixture. The Taylor marl is rather high in lime and low in silica, as are most of the samples of Del Rio clay and clay from the Webberville formation. The two terrace clays give ratios much higher than the maximum limit. Se 31 shows a very high percentage of silica, but the writer is not informed as to how much of this is free silica, a very objectionable material. The proportion of alumina and iron oxide is much too low to give promise as a cement material, and the fact that it is so low suggests that a large proportion of the silica does occur in a free state. Attention should be called to the analyses Cy 32 and Cy 27, which seem to have been made upon the most promising samples of clay in the whole series.

ECONOMIC RELATIONS.

For the economical operation of a Portland cement plant in this vicinity operating costs must be kept as low as possible in order to compete with established plants at Dallas, San Antonio, and El Paso, Tex., and also to compete occasionally with eastern cements that are brought by water to Galveston and with cements imported from Germany. It is therefore probably out of the question to consider collecting the limestone and shale from separated localities, although in this way the most suitable combinations of materials might be obtained. The problem resolves itself into one of finding suitable materials adjacent to each other, and of course the more favorably situated with regard to transportation facilities the better. The combinations of adjacent formations that are most logical are Georgetown and Del Rio, Austin and Eagle Ford, and Austin and Taylor. If combinations of materials from any two of these formations are found, on further test, to make good Portland cement, there should be no difficulty in finding ideal manufacturing sites in the vicinity of Austin. All the materials are comparatively soft and it should be possible to grind them very finely without great expenditure of power. Petroleum is the fuel that would probably be most suitable and available in this region. The limestone, clay, and shale that have been mentioned here occur in abundant quantities in the region. Their distribution is shown in detail in the geologic folio (No. 76) on the Austin quadrangle.

ANALYSES.

The analyses in the following table of rocks in the vicinity of Austin that may be of value for making Portland cement were made by P. H. Bates and A. J. Phillips, in the United States Geological Survey structural-materials laboratories at St. Louis, Mo., in 1908.

The second table contains analyses of rocks at Dallas and San Antonio, Tex., used for making Portland cement, as well as analyses of the clinker and fresh cement made at Dallas. These data are inserted for purposes of comparison.

Analyses of rocks from vicinity of Austin, Tex., possibly of value for making Portland cement.

Register No.	Material.	Formation.	Thickness sampled.	SiO_2.	Al_2O_3.	Fe_2O_3.	MnO.	CaO.	MgO.	SO_3.	Na_2O.	K_2O.	H_2O at 100° C.	Loss on ignition.	Total.	Ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
			Feet.													
Se 322	Limestone	Georgetown limestone	....	11.31	5.89	0.77	0.08	42.86	1.03	Tr.	0.26	0.47	0.51	37.32	100.50	1.70
Se 328	do	do	....	4.32	3.22	.57	.04	40.57	7.63	.12	.10	.10	.28	43.20	100.15	1.11
Se 329	do	do	12	10.39	3.13	1.03	.03	35.09	11.42	.44	....	.24	.49	38.13	100.39	2.49
Se 330	do	do	14	1.38	4.20	.57	.03	49.50	1.77	.13	0.0	.39	.38	41.91	100.26	.29
Se 331	do	do	12	8.09	3.94	.83	.03	46.62	.94	.08	0.0	.39	.75	38.57	100.24	1.69
Se 332	do	do	30	10.33	4.75	1.50	.07	43.25	.69	.06	.05	.67	.41	38.27	100.05	1.47
Cy 15	Clay	Del Rio clay	20	41.20	16.12	3.41	.05	16.36	1.26	.28	.24	1.44	2.32	17.50	100.18	2.11
Cy 16	do	do	20	42.56	15.34	5.28	.04	14.26	1.01	.47	.57	1.21	2.25	17.29	100.28	2.06
Cy 17	do	do	20	40.86	14.92	6.10	.04	14.81	.70	.86	.22	1.48	1.72	18.56	100.27	1.94
Cy 18	do	do	20	38.42	16.95	5.07	.02	14.86	.83	.39	1.04	1.64	2.59	18.59	100.40	1.74
Cy 19	do	do	22	37.64	13.80	6.00	.06	17.18	.79	.48	.72	1.28	2.56	19.86	100.37	1.91
Cy 20	do	do	20	42.10	15.90	3.35	.07	15.33	.36	.82	.23	2.03	2.57	17.37	100.13	2.19
Cy 21	do	do	10	29.48	12.25	2.69	.12	26.32	.82	.07	.16	1.61	2.17	24.61	100.30	1.96
Cy 22	do	do	16	32.91	13.42	2.69	.12	23.61	.97	.92	.15	1.73	1.70	21.98	100.20	2.04
Cy 23	do	do	20	42.09	17.78	2.46	.01	14.24	.98	1.06	1.05	.83	1.96	17.82	100.28	2.08
Cy 24	do	do	10	40.70	15.59	3.24	.07	16.41	.71	.81	.38	1.97	2.21	18.17	100.26	2.15
Cy 25	do	do	17	41.63	15.55	3.57	.07	15.68	.98	.74	.20	1.66	2.97	17.00	100.05	2.17
Se 335	Soft limestone	Austin chalk	....	10.58	5.23	1.24	.04	43.36	1.22	.12	.31	.76	.82	36.46	100.14	1.63
Se 336	do	do	....	8.94	3.00	2.27	.06	45.43	1.19	.14	.27	.45	1.23	37.28	100.27	1.70
Se 337	do	do	1	10.00	3.89	1.53	.04	43.35	1.25	.16	.50	.60	.89	37.75	99.96	1.84
Se 338	do	do	2	9.26	3.59	1.09	.05	44.76	.93	.30	....	.53	1.45	37.83	99.79	1.98
Se 339	do	do	6	5.59	2.33	.93	.06	48.59	.94	.54	.79	.45	.41	39.80	100.43	1.71
Se 340	do	do	4	7.18	3.52	1.24	.03	46.63	1.07	.19	.15	.51	.44	39.32	100.28	1.51
Se 341	do	do	6	5.76	2.70	.47	.03	49.17	.96	.71	.11	.64	.55	39.17	100.27	1.81
Se 342	do	do	....	7.80	4.64	1.14	.02	45.33	1.13	.12	....	.66	1.12	38.10	100.26	1.35
Se 343	do	do	3	6.00	1.50	1.63	.05	48.31	1.15	.24	.17	.55	.37	39.73	99.70	1.91
Se 344	do	do	1.1	6.64	3.55	1.19	.06	47.23	1.26	.18	....	.55	.44	39.12	100.22	1.40
Se 345	do	do	1.6	4.93	1.78	.67	.03	49.38	.87	.13	.71	.12	.52	40.82	99.96	.73
Se 346	do	do	5.5	6.17	2.41	.88	.06	48.55	.91	.08	.06	.49	.35	39.84	99.80	1.87
Se 347	do	do	9.5	2.82	.96	.51	.09	51.39	1.10	.08	....	.22	.36	42.40	99.93	1.95
Se 348	do	do	4.8	6.76	2.83	.67	.03	47.54	.76	.12	....	.40	.47	40.33	99.91	1.93
Se 349	do	do	5.5	4.31	1.89	.52	.03	49.54	.84	.70	.03	.49	.77	40.70	99.82	1.79
Se 350	do	do	7.5	2.28	.57	.56	.04	52.14	1.22	.12	....	.02	.37	42.54	100.17	2.02
Se 351	do	do	8	2.87	1.09	.46	.03	52.49	.85	.10	.17	.24	.23	41.26	99.79	1.85
Se 352	do	do	4.5	3.84	1.31	.47	.03	51.29	1.03	.07	....	.28	.56	40.84	99.72	2.16
Se 353	do	do	10	4.70	1.61	.36	.03	50.01	1.09	.09	.05	.28	.37	41.27	99.86	2.40
Se 354	do	do	19.5	3.12	.92	.26	.03	51.91	.44	.52	....	.16	.20	42.84	100.40	2.64

Se 355	do	do	14.1	9.18	3.50	1.05	.05	45.22	1.13	.14	.17	.55	.67	38.02	100.28	2.02
Se 356	do	do	9	4.30	1.52	.77	.05	50.22	.97	.22	.23	.47	.27	40.88	99.90	1.88
Se 357	do	do	7.5	4.76	1.72	.62	.06	49.79	.88	.10	.06	.46	.43	40.95	99.83	2.03
Se 358	do	do	30+	10.19	3.81	1.14	.03	44.34	1.08	.22	.12	.81	.56	37.54	99.84	2.58
Se 360	do	do		6.17	2.17	.88	.09	48.66	.90	.30	.50	.21	.60	39.39	99.87	2.02
Se 362	do	do	18	5.76	1.19	.82	.01	49.85	1.30	.26		.39	.52	40.48	100.18	2.86
Se 363	do	do	11	3.82	1.30	.72	.02	50.72	1.05	.29	.14	.44	.43	41.17	100.10	1.89
Cy 29	Shaly limestone	do		7.80	2.11	1.38	.01	45.88	.85	.31	.91	1.54	1.24	38.24	100.27	2.24
Misc. 80	Marl	Taylor marl	25	36.08	18.64	4.14	.01	17.39	1.74	1.59	.19	1.49	3.09	15.77	100.13	1.59
Misc. 81	do	do	5	26.18	9.66	3.35	.07	28.15	1.28	1.20	.12	1.06	2.65	26.66	100.38	2.01
Se 361	Clay shale	Eagle Ford clay	15	17.81	6.10	2.04	.02	34.76	1.27	.92	1.60	.50	1.81	32.95	99.78	2.19
Cy 30	Shaly limestone	Pleistocene (?)		50.03	10.25	3.31	.04	13.94	1.70	.05	.54	1.80	1.94	16.48	100.08	3.69
Cy 31	do	do	5 to 15	67.98	7.90	2.27	.03	8.98	1.03	Tr.	.63	1.51	.81	9.07	100.21	6.68
Se 364	Limy shale	Eagle Ford clay	8	17.56	7.60	1.76	.02	32.59	1.28	1.08	.40	1.74	1.82	34.08	99.93	1.87
Se 365	do	do	10	16.30	6.97	1.65	.02	36.03	1.29	.89	.30	1.78	1.81	36.03	99.91	1.89
Cy 32	Clay	Del Rio clay		51.01	18.23	3.51	.02	8.87	1.54	1.03	.08	2.16	2.72	11.04	100.21	2.35
Cy 26	do	Webberville formation		36.28	13.60	1.44	.01	16.42	3.83	.16	.22	.64	7.52	20.07	100.19	2.51
Cy 27	do	do		52.57	15.97	5.23	.03	6.82	2.06	.30	1.17	2.09	4.67	9.53	100.44	2.48
Cy 28	do	do		40.38	18.69	3.62	.03	9.74	3.10	.27	.70	.77	8.21	14.63	100.15	1.89

Se 322 and Se 328 to Se 332. Property of Austin Portland Cement Manufacturing Company, 3½ miles northwest of center of Austin, Tex. (Fig. 23, I.)
Cy 15 to Cy 25. Property of Austin Portland Cement Manufacturing Company, 3½ miles northwest of center of Austin, Tex. (Fig. 23, I.)
Se 335 to Se 358. Big Walnut Creek, 8 miles northeast of center of Austin, Tex., or one-half to 1½ miles northwest of Sprinkle. (Fig. 23, D.)
Se 360. Big Walnut Creek, 9 miles northeast of center of Austin, Tex. (Fig. 23, C.)
Se 362. Lower 18 feet of ledge near mouth of small creek emptying into south side of Colorado River three-fourths mile below concrete bridge. (Fig. 23, Q.)
Se 363. Top 10 or 12 feet of ledge near mouth of small creek emptying into south side of Colorado River three-fourths mile below concrete bridge. (Fig. 23, Q.)
Misc. 80. East bank of Big Walnut Creek 2 miles below Sprinkle, or 6½ miles northeast of Austin, Tex. (Fig. 23, G.)
Misc. 81. Wagon road on hill just west of Little Walnut Creek, 4½ miles northeast of Austin, Tex., or 1 mile north of Pecan Springs. (Fig. 23, J.)
Se 361. South side of Big Walnut Creek 9½ miles northeast of Austin, Tex., or 1⅛ miles below Watters station. (Fig. 23, B.)
Cy 29. Partings from top and middle of 18-foot ledge near mouth of small creek emptying into south side of Colorado River three-fourths mile below concrete bridge. (Fig. 23, Q.)
Cy 30. Heavy calcareous clay used in making dry-pressed brick at Butler's brickyard, south side of Colorado River, near International and Great Northern Railroad. (Fig. 23, N.)
Cy 31. Light loamy clay used in making sand-mold brick at Butler's brickyard, south side of Colorado River, near International and Great Northern Railroad. (Fig. 23, N.)
Se 364. Eight feet of beds below middle of Eagle Ford clay, from bluff of small creek near International and Great Northern Railroad 1 mile south of Colorado River. (Fig. 23, P.)
Se 365. Upper 10 feet of Eagle Ford clay, from bluff of small creek near International and Great Northern Railroad 1 mile south of Colorado River. (Fig. 23, P.)
Cy 32. Bluff of Barton Creek one-third mile above its mouth, sampled above and below wagon road, near bridge. (Fig. 23, M.)
Cy 26 and 27. Wilbarger Creek, 3 miles below Manor. (Fig. 23, H.)
Cy. 28. Moores Branch of Onion Creek, 9 miles southeast of Austin, Tex. (Fig. 23, R.)

Analyses of rocks from Dallas and San Antonio, Tex., used for making Portland cement.[a]

Register No.	Material.	Formation.	Thickness sampled.	SiO_2.	Al_2O_3.	Fe_2O_3.	MnO.	CaO.	MgO.	SO_3.	Na_2O.	K_2O.	H_2O at 100° C.	Loss on ignition.	Total.	Ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
			Feet.													
Se 376	Limestone (soft)	Austin chalk	25	6.54	3.22	2.12	0.04	46.72	0.61	0.55	0.38	0.59	0.49	38.64	99.90	1.22
Se 377	do	do	15–20	9.08	4.59	2.23	.11	44.44	.62	.07	.74	.72	.38	36.80	99.78	1.33
D 1	do	do		3.64	2.42			50.92	.46	b.67				42.10		1.50
D 2	Limestone (shaly)	do		12.78	8.22			40.22	.91	b.68				36.26		1.55
D 3	Limestone (soft)	do		3.74	2.74			51.11	.58	b.10				44.70		1.36
D 4	do	do		12.70	8.54			41.33	.62	b.10				36.02		1.48
Se 378	Shale (top beds)	Eagle Ford clay	8–10	45.07	15.78	4.92	.02	7.98	1.18	9.71	.08	1.70	6.51	6.89	99.84	2.23
Se 379	Shale	do	23	56.71	19.74	5.74	.02	1.28	1.91	.25	.36	1.67	4.00	8.62	100.30	2.53
D 5	Shale (top beds)	do		64.71	20.80	4.15		1.00	.31	b.72				6.67		2.59
D 6	Shale (bottom)	do		57.74	21.49	7.05		1.66	2.47	b1.27				8.11		2.02
D 7	Shale (quarry run)	do		60.09	22.20			2.80		b.31				12.35		2.70
Ct 711a	Portland cement (clinker)			21.82	11.27	2.59	.06	62.36	.50	.03	.16	.49	.02	.90	100.20	
Ct 711b	Fresh Portland cement			21.35	9.90	1.91	.10	62.78	.72	1.70	.08	.41	.10	1.20	100.25	
SA 1	Limestone (soft, weathered).	Austin chalk	3–5	20.09	2.40	1.20		40.82		b.07	1.45					5.55
SA 2	Limestone (soft, fresh)	do	3–5	22.90	1.70	0.70		40.77		b2.10	2.0					9.54
SA 3	Limestone	do	20+	16.50	6.10	1.00		44.31								2.32
SA 4	do	do	3–5	22.1	2.90			40.82		b.70						7.62

[a] Analyses Se 376 to Se 379 and Ct 711a and Ct 711b by R. H. Bates and A. J. Phillips, U. S. Geol. Survey laboratories, St. Louis, Mo., 1908; D 1 to D 8 made at laboratory of Texas Portland Cement Company, Dallas, Tex.; SA 1 to SA 4 made at laboratory of Alamo Cement Company, San Antonio, Tex.

[b] Sulphur (S).

Se 376, Se 377, D 1 to D 4, Se 378, Se 379, D 5, D 6, D 7: Quarry of Texas Portland Cement Company, near Dallas, Tex.
Ct 711a, Ct 711b: From new mill of Texas Portland Cement Company, Dallas, Tex., March, 1908.
SA 1 to SA 4: Quarry of Alamo Cement Company, San Antonio, Tex.

BUILDING STONE.

THE SLATES OF ARKANSAS.

By A. H. Purdue.

THE SLATE INDUSTRY IN ARKANSAS.

As early as 1859 a slate quarry was opened in Arkansas, northwest of Little Rock. A company was formed to quarry the slate for roofing purposes, but the product was found incapable of standing the weather. Many years ago a quarry was opened near the mouth of Glazierpeau Creek, 12 miles northwest of Hot Springs, but no reliable report of this slate having been utilized has been obtained. From 1885 to 1908 several quarries were opened up in the western part of Pulaski County and the eastern part of Saline County, and from some of these a small amount of roofing slate has been shipped.

In 1902 the Southwestern Slate and Manufacturing Company was organized to operate in Polk and Montgomery counties. Title was acquired to land to the extent of about 1,600 acres. A large amount of money was subscribed, which was expended in building roads, erecting buildings, installing machinery, and various other improvements necessary for conducting an extensive business when shipping facilities, which were expected soon, could be had. Disappointment in obtaining transportation resulted in the reorganization of the company in 1903. In this reorganization the name was changed and the Southwestern Slate Company, which succeeded to all the property of the first company, purchased 320 acres more of land. The operating plant, located at Slatington, Ark., contains one saw, one planer, and one rubbing bed. To the present time (1910) only milling slate has been produced, a considerable amount of this having been put on the market, principally for electrical uses.

The work of the Southwestern Slate and Manufacturing Company and its successor gave an impetus to slate prospecting. A large number of titles were acquired to slate lands, and more or less prospecting was done on many of them, among which the following are mentioned:

In 1900 the Altus Slate Company opened a quarry in Polk County in sec. 11, T. 3 N., R. 23 W., about 7 miles west of Big Fork post-office. After working for about a year it was discontinued. The writer is informed that no slate was shipped from this quarry. Near by is another quarry that was owned by the Standard Slate Company.

After working for some time this company went into bankruptcy, and the property was sold.

Subsequently the Gulf Slate Company, of Indianapolis, Ind., opened a quarry in sec. 12, T. 3 N., R. 29 W. Some buildings were erected and a good deal of work was done here, but no slate was shipped. Nothing was being done at the time of the writer's visit (summer, 1907).

Near Big Fork post-office there are numerous smaller openings, most of which were made from 1900 to 1906.

In 1904 the J. R. Crowe Coal and Mining Company opened small quarries in sec. 36, T. 3 S., R. 27 W. At the same time small buildings were erected for tenant houses, and a larger one for a hotel. At the time of the writer's visit (1907) no work was being done and no slate had been shipped from this place.

In the winter of 1902 the Ozark Slate Company began operations in Garland County, about 12 miles west of Hot Springs. A plant was erected consisting of a hoisting engine, two wire trams, each about 500 feet long, and a few buildings. The most important of these contained the boiler and engine, two saws, one planer, one band saw, one rubbing bed, and six slate trimmers. A great deal of quarrying was done here. At the time of the writer's visit to this plant (1907) it was in charge of the quarry foreman, but no work was being done.

From 1900 to 1905 a great deal of prospecting was done in Montgomery and Garland counties in the neighborhood of Crystal Springs. About the same time several prospects were opened up farther west, in the vicinity of Plata and Alamo, Montgomery County, but no slate has been shipped from any of these.

THE ORIGIN OF SLATE.

Slate may be defined as any rock in which the property of parting along parallel planes is developed to such an extent that the rock may be split into thin plates with even surfaces. This property of parting is called slaty cleavage.

Slaty cleavage is a secondary property of rocks and is developed in those of fine-grained and soft material. Most such material is of sedimentary origin. It was transported from the land by streams and spread out over the bottom of the sea as mud, in thin layers, one upon the other. Some of these deposits covered wide areas and reached many feet in thickness. In course of time they, with the other rocks above and below them, were elevated into land areas.

Where slaty cleavage was not developed in the course of the elevation the layers in which the mud was spread out have remained in their original condition, except that they generally have been hardened into shale; but where slaty cleavage was developed in the process of elevation all traces of the original layers may have been obliterated. Under such conditions the only partings are those along the cleavage planes. These partings usually are at an angle to the bedding planes and consequently cut across the original mud layers, though in some rocks they are parallel to those layers.

If, in the elevation of a land area, the only forces are those acting in vertical lines, so that the strata remain horizontal, slaty cleavage is not induced; but if there are forces acting horizontally, causing the strata to be folded, slaty cleavage may be developed. It follows that slates do not occur in regions of horizontal rocks; nor can they by any means be expected in all regions of folded rocks.

THE SLATE AREA OF ARKANSAS.

The area of Arkansas in which the surface rocks are folded, and in which consequently slate might be looked for, is in the central-western part of the State (fig. 24). It lies between Arkansas River and the northern parts of Sevier, Howard, Pike, and Clark counties, west of the St. Louis, Iron Mountain and Southern Railroad.

It must not be understood that all parts of this area contain slate; for in the formation of slate not only must dynamic agencies so act upon the rocks as to compress and throw them into folds, but the originally deposited material from which the rocks were formed must have been mechanically and chemically suited to undergo metamorphism into slate. Most slate is metamorphosed shale. Shale is common over all parts of the area mentioned above, and folding in many parts has been so intense as to cause the strata to stand on edge or even to be overturned; yet slate is confined to a comparatively small area, because within that area only were the shales of such a nature as to permit their alteration into slate.

The area in which the slates of Arkansas are situated includes a part of the Ouachita Mountains and extends from the vicinity of Little Rock westward to that of Mena. Its length is about 100 miles and its average width 15 miles. It lies mainly in Saline, Garland, Montgomery, and Polk counties. The St. Louis, Iron Mountain and Southern Railway runs near the eastern border, and the Kansas City Southern Railway near the western border. The Little Rock and Hot Springs branch of the Chicago, Rock Island and Pacific Railway enters the area. The St. Louis, Iron Mountain and Southern Railway has a branch from Malvern to Hot Springs, and the Gurdon and Fort Smith Railroad (not shown on map, fig. 24) is completed from Gurdon to Womble, a new town 2½ miles southeast of Black Springs, Montgomery County.

GEOLOGY OF THE SLATE AREA.

TOPOGRAPHY.

The slate area of Arkansas lies in the southern part of the Ouachita Mountains. The topography is rough and consists of east-west steep-sided ridges, separated by narrow valleys. The slopes of the ridges are covered by loose, angular rocks and by timber. The crests are straight, rock covered, and destitute of timber. The valleys usually

FIGURE 24.—Map showing slate area of Arkansas.

are occupied by small streams, but the master streams, such as Caddo, Little Missouri, and Cossatot rivers, flow southward, cutting through the ridges and receiving the smaller ones along their courses.

ROCKS.

The surface rocks within the slate area of Arkansas are practically all of sedimentary origin. In the eastern part there is a small area of igneous rock at Potash Sulphur Springs, Garland County, and a larger one at Magnet Cove, Hot Spring County. A short distance beyond the eastern border of the slate region there are two small areas of igneous rock. One of these is in Saline County, about 6 miles east of Benton, and the other in Pulaski County, a short distance south of Little Rock. In numerous places throughout the eastern part of the slate area, from the town of Crystal Springs eastward, dikes of igneous rock are reported.[a] These dikes doubtless are of the same age as the larger areas of igneous rock, with which there is good reason to suppose they are connected beneath the surface. Though they are exposed in a large number of places, their actual area is so small and their effect upon the sedimentary rocks so little that for the purpose of the present report they may be dismissed from further consideration.

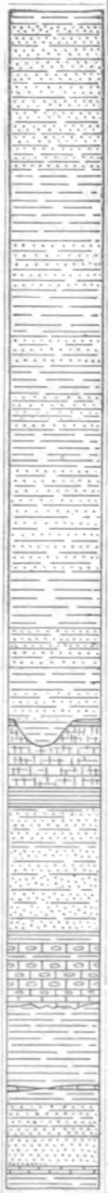
The sedimentary rocks of the area consist of shales and slates, chert, novaculite, sandstone, and a small amount of limestone. Of these the shales and slates occur in the greatest quantity, and the relative amounts of the others are in the order named. The following table presents the different rocks that occur in the area in the order of their age, with the oldest at the bottom:

Section of sedimentary rocks in slate region of Arkansas.

	Feet.
Carboniferous: Stanley shale	6,000
Unconformity.	
Age unknown:	
Fork Mountain slate	100
Arkansas novaculite	800
Missouri Mountain slate	300
Probable unconformity.	
Ordovician:	
Blaylock sandstone	1,500
Polk Creek shale	100
Bigfork chert	700
"Stringtown" shale	100
Unconformity.	
"Ouachita" shale	900
Crystal Mountain sandstone	700
Probable unconformity.	
Age unknown:	
Collier shale (observed thickness)	200
	11,400

[a] Geol. Survey Arkansas, vol. 2, 1890, pp. 409-427.

The columnar section (fig. 25) presents in compact form the age, thickness, and character of the formations.



Period.	Formation.	Thickness (feet).	Character of rocks.
Carboniferous (Pennsylvanian?).	Stanley shale.	6000	Greenish clay shale, locally black slate near the base, and greenish quartzitic sandstone.
Age unknown.	Fork Mountain slate.	0-125	Gray slate with thin beds of siliceous material.
	Arkansas novaculite.	0-800	Massive white and variegated novaculite with alternating flint and shale layers in the upper half.
	Missouri Mountain slate.	75-300	Mainly red slate with green slate in the basal portion.
Ordovician.	Blaylock sandstone.	0-1500	Greenish quartzitic sandstone alternating with brownish-black shale layers.
	Polk Creek shale.	0(?)-100	Black fissile and sandy graptolitic shale.
	Bigfork chert.	700	Gray to black chert interstratified with black shale layers at the top.
	"Stringtown" shale. "Ouachita" shale.	900-1000	Black graphitic shale, with slaty cleavage, containing sandstone and limestone layers near the base and patches of blue limestone locally conglomeratic near the top.
	Crystal Mountain sandstone.	700	Sandstone interstratified with black shale. Massive, white, coarse-grained sandstone.
Age unknown.	Collier shale.	200+	Black, graphitic clay shale, containing blue conglomeratic limestone near the top.

FIGURE 25.—Columnar section of the Ouachita area.

FOLDING.

That portion of the Ouachita area in which slates occur is intensely folded. In the process of folding there was produced one master anticline, or upward fold, known as the Ouachita anticline.[a] The highest part of this anticline lies between Black Springs, Montgomery County, and Ouachita River in Garland County, passing north of the town of Crystal Springs. Though this anticline pitches to the west in the vicinity of Black Springs, it continues as a marked feature of the structure to the western portion of the State. Upon the north and south slopes of this anticline are numerous smaller folds, which with the main arch form an anticlinorium. An idea of the general structure of the region can be had from figure 26.

The minor anticlines and synclines are comparatively narrow. So intense were the dynamic forces that these folds are closely compressed. The rock layers nearly everywhere stand at a high angle, and in many places they are on edge. Indeed, as a rule the strata not only have been lifted from the horizontal to the vertical position, moving through an arc of 90°, but have been shoved over beyond the vertical position or overturned. This may be seen by reference to figure 26. The over-

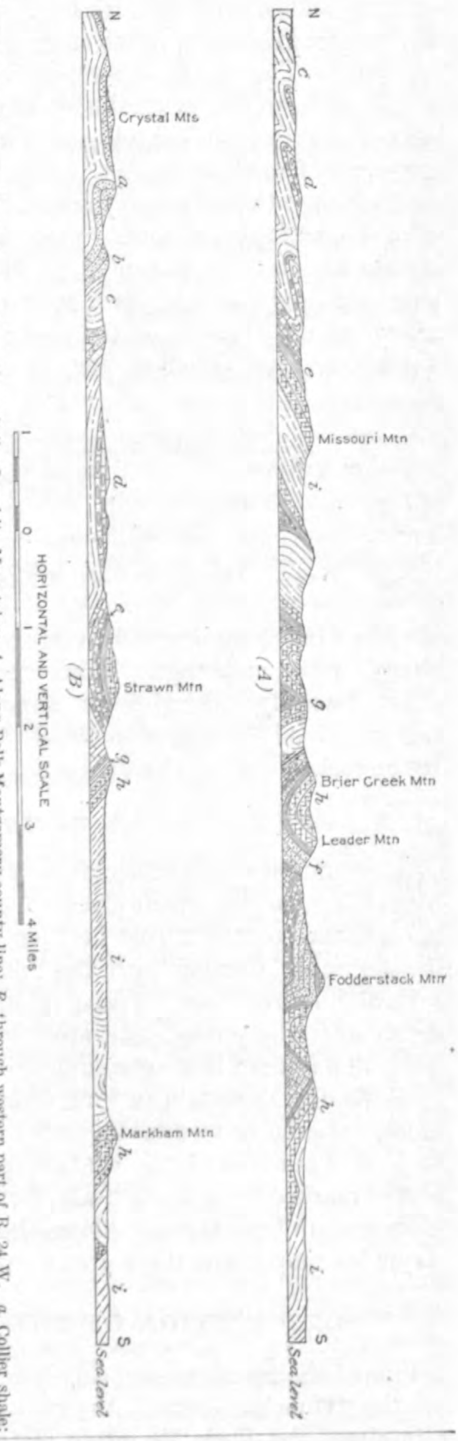


FIGURE 26.—North-south structure sections through the Ouachita Mountains: *A*, Along Polk-Montgomery county line; *B*, through western part of R. 24 W. *a*, Collier shale; *b*, Crystal Mountain sandstone; *c*, "Ouachita" shale and "Stringtown" shale; *d*, Bigfork chert; *e*, Polk Creek shale; *f*, Blaylock sandstone; *g*, Missouri Mountain slate; *h*, Arkansas novaculite; *i*, Stanley shale.

[a] Geol. Survey Arkansas, vol. 3, 1890, pp. 273 et seq.

turning and compression are so complete that the rock layers on either side of the axes of the folds are parallel, forming what are known as isoclines. This produces a repetition of the strata which is confusing to one not familiar with the structure but which must be taken into account by all who intelligently prospect the region for geologic products of any kind.

An idea of the nature of these folds may be obtained from figure 27. The character of the folds by no means persists along their axes but differs within short distances, so that two cross sections of the same mountain only a mile apart would in many cases be different. In other words, the dip of the rocks may differ greatly within short distances. An anticline may break up into two, a symmetrical

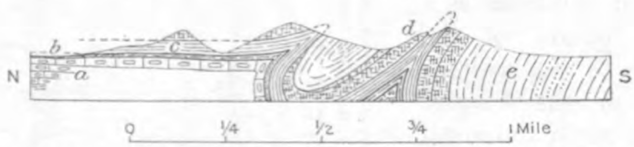


FIGURE 27.—North-south section through Missouri and Statehouse mountains, 1 mile east of Slatington, Montgomery County, Ark. *a*, Bigfork chert; *b*, Polk Creek shale; *c*, Missouri Mountain slate; *d*, Stanley shale.

anticline may pass into an overturn, or an anticline or syncline may sharply pitch or plunge. It is common for two folds to overlap each other laterally, plunging in opposite directions. This structural feature, aided by erosion, produces the zigzag topography so common in the eastern part of the slate area.

FAULTING.

As would be expected, the rocks of the region could not everywhere, by folding, adjust themselves to the great dynamic force exerted upon them, so that thrust faulting is very common. The faults are in the main parallel with the folds. In some places the throw is several hundred feet. These faults have not been worked out in detail over the entire slate area, but among them are several that occur in a faulted belt extending from the valley of Long Creek, south of McKinley Mountain in Polk County, south of east for at least 25 miles, apparently terminating near the main branch of Caddo Creek. In Polk County and the western part of Montgomery County this belt is marked by a single fault, but in the eastern part of range 27 it breaks up into three. Along the line of Bearden, Tweedle, and Reynolds mountains there are two parallel faults.

DESCRIPTION OF THE ARKANSAS SLATES.

Five of the formations of the Ouachita Range contain slate. These are the "Ouachita" shale, the Polk Creek shale, the Missouri Mountain slate, the Fork Mountain slate, and the Stanley shale. Only the last-named three have been prospected to any extent, and most of the prospecting and developing has been done in the Missouri Mountain slate.

"OUACHITA" SHALE.

The "Ouachita" shale is the surface rock about Black Springs and elsewhere in the Caddo Creek basin, Montgomery County. Its area over the Ouachita Range is not known but is greater than the area of all the other slate formations combined. As its name implies, it is mainly a shale, generally showing no indication of slaty cleavage; but in parts of it slaty cleavage is well developed and in such parts is conspicuous in the stream beds, by the roadside, and in other places where the formation is exposed. The cleavage usually is at a high angle to the bedding, and as it appears to be best developed in those parts of the formation where the layers are of different color, "ribbons" are very common in it. These consist of alternating green and blue bands from one-fourth inch to 2 inches thick and are due to original differences in the color of the shale from which the slate was formed. In places this slate is sufficiently indurated for temporary roofing, but generally it is too soft to withstand the weathering agencies long. It is also, in all places where observed, so closely jointed as to prevent the quarrying of blocks of commercial size. Besides, its banded or "ribbon" structure would render it undesirable commercial slate, even though it possessed all the other requisite qualities.

POLK CREEK SHALE.

The Polk Creek shale is only about 100 feet thick, and owing to this fact and to the folded nature of the region it outcrops as narrow belts, which usually are found along the bases of the mountains. This formation, like the Ouachita, is commonly a shale, but locally slaty cleavage is well developed in it. In places this slate is banded, but in others it is of a uniform black color, is hard, has a metallic ring, and contains large numbers of graptolite fossils. Jointing is very common in both the shale and the slate. On account of the comparatively small amount of this formation in which slaty cleavage is well developed and the abundance of the joints, it does not give much promise as a producer of commercial slate; there may, however, be parts from which such slate could be secured.

MISSOURI MOUNTAIN SLATE.

The Missouri Mountain slate is the formation that has been most prospected for slate. Though it does not enter into the minute folding of the region, as does the Polk Creek shale, it partakes of the principal folding. (See fig. 28.) It is widespread over the area, and outcrops in many places near the mountain bases, though it may be found high up on the slopes, or even in notches of the crests of the ridges.

This slate has been rather extensively prospected all the way from Board Camp Creek, in Polk County, eastward to Ouachita River, in Garland County. The point at which it has been most extensively worked is Slatington, Montgomery County, but there are other prospects in it of considerable magnitude. It has been so widely prospected not only on account of its promising character as a source of commercial slate, but because of the favorable location and nature of its outcrops, most of which are in bluffs and well up on the mountain slopes. As the slate is exposed in the face of the bluffs, no labor or expense of removing surface material is imposed upon the prospector; and the height of the outcrop on the slope permits all waste material to be easily dumped. It varies in thickness from about 300 feet to 50 feet or less. The thickest portion is along the central line of the Ouachita Range, from which it thins out southward and probably northward. In some of the closely compressed anticlines it is

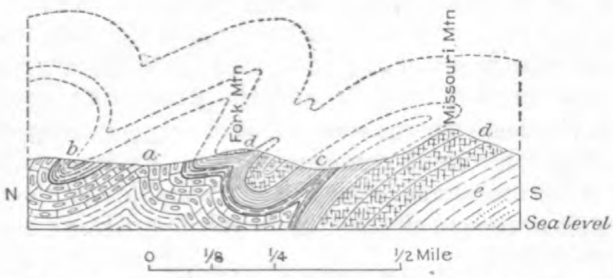


FIGURE 28.—North-south section through Fork Mountain, Arkansas, T. 3 S., R. 28 W., showing the folded nature of the Missouri Mountain slate. *a*, Bigfork chert; *b*, Polk Creek shale; *c*, Missouri Mountain slate; *d*, Arkansas novaculite; *e*, Stanley shale.

folded over upon itself, and in such places its thickness appears to be double what it actually is. Such is the case in that part of Caddo Mountain that lies south of Wagner Creek, in sec. 15, T. 4 S., R. 26 W., where the slate is exposed for 600 feet, lying between heavy walls of the Arkansas novaculite.

The formation produces both red and green slate. Though both kinds may and commonly do occur in the same quarry, the red is predominant. It is a clay slate of remarkable homogeneity, sandy or other impure layers being absent. In color it varies from scarlet to dark red, but that of any particular quarry is likely to be uniform. In exposed surfaces it presents a rich, pleasing appearance. On account of its homogeneous nature, no traces of the original bedding are to be seen. This fact, together with its great thickness, make it impracticable in most places to determine the direction of the cleavage with reference to the bedding planes. In some places where it is near the overlying Arkansas novaculite the cleavage is plainly parallel with the bedding; in other places it is oblique. It is probable that the cleavage usually is oblique to the bedding.

In most parts this slate is intersected by numerous joints that run in all directions, but in favorable places these are not so common as to prevent the quarrying of large blocks. The slate cleaves with fairly even surfaces and can readily be split into sheets a quarter of an inch thick and less. Some parts have a semimetallic ring, but most of it produces a dull sound when struck. In many places the intense folding of the region has produced short, wavelike wrinkles in the slate, which quarrymen call "curl" and which are avoided in prospecting. Any quarry showing a considerable amount of this may as well be abandoned. In other parts two sets of cleavage planes are locally developed. These may be detected by the splitting up of the exposed surfaces into small prisms shaped like shoe pegs. Such exposures as this should be avoided by the prospector.

Sheets of a considerable size are seldom found on the slopes, and hence it appears that this slate weathers readily. If this inference is correct, the slate could not be used for roofing purposes. It is hoped, however, that this statement will not prevent anyone from experimenting with it by putting it into actual use for roofing, as this alone can determine its fitness for such purposes. In the only instance that has come to the writer's attention of shingles of this slate being used for roofing purposes, they went to pieces after a few years' service. But the result of this one trial should not be taken as final, for slate from another quarry might last for many years. The best way to test it is for the people of the slate area to use it on small and temporary outbuildings. Such a test should be made of the slate of every quarry that will produce shingles; for if any of this slate should be discovered with lasting qualities, its beautiful color would at once put it in great demand, especially for buildings with gray walls or trimmings.

At present slate is in demand for inside fittings, such as laundry tubs, wainscoting, lavatories, switchboards, floor tile, etc. This slate is too soft for the last purpose named, but is well adapted for all the other purposes, and especially for switchboards, for which practically all the product of the quarries at Slatington has been used. Several samples of this slate have been tested for conductivity. The result of the tests is published elsewhere in this report (p. 330).

Because of its softness and homogeneity, this is altogether a desirable slate to work. It splits, saws, and planes easily, and soon takes a polish on the rubbing bed. But in the process of drying, after having been taken from the rubbing bed, it is liable to check, and the amount thus lost greatly reduces the profit of working it. This checking is sometimes at right angles to the cleavage and sometimes parallel with it. That is to say, the worked pieces may either crack perpendicularly to their faces, or they may split apart. If some method of working can be devised that will avoid this checking, the slate industry of Arkansas will become an important and profitable one.

FORK MOUNTAIN SLATE.

The Fork Mountain slate lies normally above the Arkansas novaculite, but owing to overturning it commonly lies beneath that formation on the mountain slopes. If on one side of a valley or a ridge it lies above the novaculite, on the opposite side it is most likely to lie below. On account of an unconformity at its top the formation is not everywhere present, and for the same reason it varies greatly in thickness. Its maximum thickness has not yet been ascertained, but in sec. 5, T. 4 S., R. 27 W., where it outcrops well up on the mountain slope, it is known to exceed 100 feet. Where the formation dips into the mountain it can easily be detected, for there it forms bluffs; but where it dips with the mountain slope it may be overlooked.

This is a hard slate, generally gray, though portions of it on weathered surfaces are green or chocolate. Thin sandy or quartzitic layers are numerous. The cleavage usually is well developed and occurs at all angles to the bedding planes. "Ribbons" not uncommonly occur. The slate has great strength and toughness and is highly sonorous. In most places jointing is so common as to render the slate worthless, but it must not yet be concluded that exploiting will find it universally so. Prospectors should not neglect this slate. Though it certainly never would do for milling purposes, if found sufficiently free from joints and sandy seams it would make shingles of exceptional quality.

STANLEY SHALE.

The Stanley shale, as the name implies, is almost everywhere a shale; but in some parts of the closely folded synclines of the Ouachita Range it is altered into true slate. This slate has been rather extensively prospected near Slatington and at several places in the southeastern part of Polk County. It is blue to black in color. The cleavage, where it is best developed, is remarkably fine, permitting the slate to split into very thin sheets with smooth, beautiful surfaces. Except the quarry near Slatington and one east of Bear belonging to the Ozark Slate Company, none of any size has been opened in this formation. Nor has any of the slate, so far as is known to the writer, been used for roofing purposes. From the general observations in the field it appears that this formation does not give much promise of producing commercial slate. Though the formation is a thick one, only a small portion of it has been altered to slate, and this, where observed, is not sufficiently indurated to last long on a roof.

TESTS OF ARKANSAS SLATE.

ELECTRIC TESTS.

Six pieces of red slate from Slatington, Ark., were submitted to W. N. Gladson, professor of electric engineering in the University of Arkansas, who reported the following electric tests:

These pieces of slate were tested in comparison with three pieces of gray slate taken at random from old switch bases in the university electric laboratory. A piece 1 centimeter cube was cut from each sample and these were numbered consecutively from 1 to 9, Nos. 1, 3, and 4 being gray slate. In preparing the cubes metallic particles were found in samples 4 and 6, and Nos. 5 and 6 were so easily split that it was difficult to obtain a centimeter cube.

The pieces of red slate as received were smooth blocks 4 by 5 inches by five-eighths of an inch, neither varnished nor in any way filled. They were red or reddish brown, were much softer than the gray slate, and split much more readily. All samples tested were dry and appeared to be seasoned. The method of measuring the resistance of these centimeter cubes was as follows:

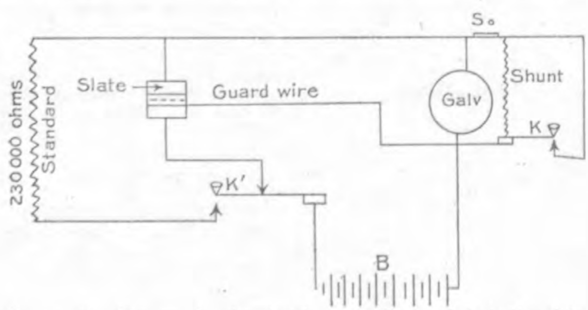


FIGURE 29.—Diagram showing electric connections made in testing slate.

A block of paraffin wax was attached to the center of a glass plate, which in turn was thoroughly insulated from the table by glass strips piled across one another. In the top of the paraffin block an opening was cut 1 centimeter square and about 3 millimeters deep. In the bottom of the cavity thus formed four copper supports were embedded so that their top surfaces were in the same plane, about 1 millimeter below the top of the paraffin cup. A drop of mercury coming about flush with the copper supports in this cavity formed one terminal for making electric connection to the slate cube. Contact with the opposite face was made by placing a well-amalgamated zinc plate 1 centimeter square on top of the cube. This arrangement insured equal contact with each slate cube under test.

The galvanometer used was of the D'Arsonval type, and had a working constant of 70,533 millimeters on the scale 1 meter distant through 1 megohm resistance. The electromotive force was furnished by storage cells and was kept constant at 42 volts during the experiment. The connections were made as shown in figure 29.

To avoid leakage over the surface of the slate a guard wire was connected as shown. All readings were taken after the deflections became constant; in some tests they did not become so until half an hour after electrification.

The results of the test are shown in the following table, from which we find the average resistance of all samples to be 1,224.2 megohms per cubic centimeter. The average resistance of the three gray samples was 1,180, and of the six red-slate samples 1,267.8 megohms per cubic centimeter. Each piece tested, except No. 7, shows a different resistance between each pair of opposite parallel faces, which seems to depend on the plane of cleavage. The gray-slate samples show a decidedly higher resistance between faces of cubes perpendicular to cleavage planes, but in individual samples the distribution of resistance would be greatly affected by the presence of foreign conducting particles or seams, which are likely to be present in all slate.

Results of tests of electric resistance of slate samples.

Sample No.	Galvanometer scale deflections.			Resistance.[a]		
	Perpendicular to cleavage planes.	Parallel to cleavage planes.		Perpendicular to cleavage planes.	Parallel to cleavage planes.	
	D.	D′.	D″.	R.	R′.	R″.
	Mm.	*Mm.*	*Mm.*	*Megohms.*	*Megohms.*	*Megohms.*
1	39.0	40.0	44.0	1,808.5	1,763.3	1,603.0
2	98.0	174.0	625.0	719.7	405.3	67.1
3	171.0	185.0	283.0	414.9	381.2	249.2
4	35.0	94.0	43.0	2,015.3	750.4	1,640.3
5	104.0	47.7	39.9	678.2	1,476.3	1,767.1
6	338.9	28.0	88.0	208.1	2,519.0	801.5
7	91.0	91.0	48.0	775.0	775.0	1,469.4
8	57.0	51.0	27.0	1,500.7	1,383.0	2,612.3
9	45.0	33.0	36.0	1,567.4	2,137.3	1,959.2

[a] R, R′, and R″ correspond to the directions D, D′, and D″, respectively.

Average of Nos. 1, 3, and 4 (gray slate), 1,180.6 megohms per centimeter cube.
Average of Nos. 2, 5, 6, 7, 8, and 9 (red slate), 1,267.8 megohms per centimeter cube.
Average of all samples, 1,224.2 megohms per centimeter cube.

PHYSICAL AND CHEMICAL TESTS.

The following specimens were collected and submitted to the structural-materials testing laboratories of the United States Geological Survey at Forest Park, St. Louis, Mo., for transverse pressure, absorption, and physical tests, and for chemical analyses. The results are herewith published:

Source and color of slate samples tested.

No.	Owner.	Locality.	Color.
1	Southwestern Slate Co	E. line of NE. ¼ SE. ¼ sec. 33, T. 3 S., R. 27 W	Red.
2	do	do	Green.
3	M. J. Harrington	Sec. 24, T. 3 S., R. 29 W	Black.
4	Southwestern Slate Co	SE. ¼ SE. ¼ sec. 33, T. 3 S., R. 27 W	Red.
5	M. J. Harrington	Sec. 24, T. 3 S., R. 29 W	Black.
6	M. W. Jones	do	Green.
7	do	do	Do.
8	do	do	Red.
9	do	do	Reddish brown.
10	do	do	Red.
11	C. B. Baker	NE. ¼ sec. 18, T. 3 S., R. 28 W	Buff.
13	M. W. Jones	Sec. 24, T. 3 S., R. 29 W	Red.

Results of physical tests on Arkansas slate.

Field No.	Register No.	Individual specimen No.	Transverse tests. Dimensions. Width.	Transverse tests. Dimensions. Depth.	Transverse tests. Span.	Transverse tests. Conditions at maximum load. Load at center.	Transverse tests. Conditions at maximum load. Deflection at center.	Transverse tests. Conditions at maximum load. Modulus of rupture.	Transverse tests. Modulus of elasticity (constant nearly to maximum).	Absorption tests. Weight ratio of absorption. 30 minutes.	Absorption tests. Weight ratio of absorption. 24 hours.	Absorption tests. Weight ratio of absorption. 48 hours.	Absorption tests. Volume ratio of absorption. 30 minutes.	Absorption tests. Volume ratio of absorption. 24 hours.	Absorption tests. Volume ratio of absorption. 48 hours.	Specific gravity. True.	Specific gravity. Apparent.	Absolute porosity $1 - \frac{A.s.g.}{T.s.g.}$	Weight per cubic foot.
			Inches.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Lbs. per sq. inch.*											*Pounds.*
1	Misc. 141..	1	2.00	0.95	9	322	0.0190	2,410	2,100,000	0.0017	0.0189	0.0189	0.0047	0.0511	0.0513	2.863	2.714	....	169.1
		2	1.98	.97	9	674	.0148	4,880	4,640,000	.0005	.0175	.0193	.0014	.0475	.0523	2.859	2.712	....	169.0
		3	1.98	.98	9	854	.0196	6,060	4,250,000	.0011	.0164	.0786	.0031	.0439	.0500	....	2.689	....	167.5
		Av.	....	....	....	....	....	4,450	3,660,000	.0011	.0176	.0189	.0031	.0475	.0512	2.861	2.705	0.0545	168.5
2	Misc. 142..	1	1.94	1.00	9	920	.0134	6,400	6,430,000	.0004	.0089	.0105	.0010	.0243	.0286	2.813	2.738	....	170.6
		2	1.97	.98	9	959	.0150	6,840	6,040,000	.0004	.0075	.0095	.0012	.0205	.0260	2.816	2.747	....	171.1
		3	1.99	.97	9	920	.0170	6,630	5,470,000	.0003	.0087	.0101	.0009	.0238	.0276	....	2.744	....	171.0
		Av.	....	....	....	....	....	6,620	5,980,000	.0004	.0084	.0100	.0010	.0229	.0274	2.815	2.743	.0256	170.9
3	Misc. 143..	1	1.98	.28	12	59	.0430	6,840	13,420,000	.0037	.0160	.0189	.0094	.0409	.0481	2.696	2.550	....	158.9
		2	1.95	.26	12	56	.0790	7,640	8,820,000	.0012	.0114	.0146	.0031	.0293	.0375	2.702	2.564	....	159.7
		3	2.05	.27	12	80	.0855	9,640	11,030,000	.0041	.0167	.0201	.0105	.0425	.0512	....	2.544	....	158.5
		Av.	....	....	....	....	....	8,040	11,090,000	.0030	.0147	.0179	.0077	.0376	.0456	2.699	2.553	.0541	159.0
4	Misc. 144..	1	2.07	.30	12	93	.0600	8,990	11,820,000	.0026	.0113	.0121	.0072	.0310	.0332	2.862	2.748	....	171.2
		2	1.98	.27	12	64	.0560	7,980	12,420,000	.0009	.0087	.0114	.0025	.0241	.0315	2.857	2.776	....	173.0
		3	1.99	.29	12	80	.0615	8,600	11,570,000	.0013	.0112	.0122	.0036	.0307	.0334	....	2.741	....	170.8
		Av.	....	....	....	....	....	8,520	11,940,000	.0016	.0104	.0119	.0044	.0286	.0327	2.860	2.755	.0367	171.7
5	Misc. 145..	1	1.94	.85	12	210	....	2,700	2,900,000	.0023	.0120	.0157	.0058	.0305	.0402	2.705	2.557	....	159.3
		2	2.04	.77	12	279	.0405	4,150	3,150,000	.0033	.0153	.0193	.0083	.0390	.0491	2.704	2.544	....	158.5
		3	1.94	.78	12	388	.0335	5,920	6,010,000	.0024	.0121	.0156	.0062	.0309	.0397	....	2.553	....	159.1
		Av.	....	....	....	....	....	4,260	4,020,000	.0027	.0131	.0169	.0068	.0335	.0430	2.705	2.551	.0570	159.0
6	Misc. 146..	1	2.04	1.09	12	400	.0252	2,970	2,620,000	.0014	.0076	.0114	.0040	.0210	.0314	2.860	2.771	....	172.6
		2	2.03	1.02	12	318	.0134	2,710	4,810,000	.0010	.0081	.0093	.0027	.0225	.0257	2.854	2.767	....	172.4
		3	2.03	1.01	12	791	.0233	6,880	6,920,000	.0015	.0080	.0093	.0041	.0221	.0257	....	2.769	....	172.5
		Av.	....	....	....	....	....	4,190	4,780,000	.0013	.0079	.0100	.0036	.0219	.0276	2.857	2.769	.0308	172.5
7	Misc. 147..	1	2.03	.24	12	35	.0660	5,390	9,240,000	.0010	.0089	.0109	.0028	.0243	.0300	2.805	2.739	....	170.6
		2	2.07	.23	12	57	....	9,370	10,290,000	.0013	.0089	.0107	....	....	....	2.810	....	....	....
		3	1.96	.24	12	40	.0740	6,380	8,060,000	.0011	.0090	.0113	.0029	.0246	.0310	....	2.733	....	170.3
		Av.	....	....	....	....	....	7,050	9,200,000	.0011	.0089	.0110	.0029	.0245	.0305	2.808	2.736	.0256	170.5
9	Misc. 149..	1	1.99	.17	7	48	.0317	8,760	13,150,000	.0010	.0073	.0088	.0029	.0203	.0244	2.849	2.764	....	172.2
		2	2.00	.14	7	47	.0358	12,590	19,530,000	.0010	.0081	.0091	.0029	.0227	.0256	2.845	2.806	....	174.8
		3	2.00	.22	4	120	....	7,440	....	.0009	.0082	.0091	.0026	.0229	.0255	....	2.789	....	173.8
		Av.	....	....	....	....	....	9,600	16,340,000	.0010	.0079	.0090	.0028	.0220	.0252	2.847	2.786	.0214	173.6

11	Misc. 150..	1	1.97	.53	9	139	.0181	3,390	4,720,000	.0183	.0410	.0410	.0467	.1045	.1045	2.828	2.552	....	159.0
		2	1.94	.51	9	155	.0181	4,150	6,090,000	.0185	.0402	.0404	.0471	.1023	.1029	2.830	2.546	....	158.6
		3	1.93	.52	9	140	.0206	3,620	4,500,000	.0084	.0365	.0365	.0216	.0941	.0941	....	2.576	....	160.5
		Av.	....	....	....	....	....	3,720	5,100,000	.0151	.0392	.0393	.0385	.1003	.1005	2.829	2.558	.0958	159.4
8	Misc. 148..	1	1.94	.15	7	20	.0265	4,810	9,820,000	.0016	.0094	.0101	.0045	.0263	.0283	2.863	2.801	....	174.5
		2	2.04	.17	7	36	.0330	6,410	9,410,000	.0010	.0081	.0096	.0028	.0227	.0272	2.866	2.822	....	175.8
		3	2.02	.17	7	32	.0250	5,760	15,810,000	.0010	.0089	.0098	.0027	.0252	.0279	....	2.838	....	176.8
		Av.	....	....	....	....	....	5,660	11,680,000	.0012	.0088	.0098	.0033	.0247	.0278	2.865	2.820	.0157	175.7
10	Misc. 148..	1	1.99	.12	7	9.75	.0430	3,570	5,730,000	.0088	.0251	....	....	....	....	2.854	....	....	....
		2	1.93	.13	7	8	.0378	2,570	4,250,000	.0072	.0257	.0257	.0194	.0689	.0689	2.857	2.682	....	167.1
		3	1.97	.14	7	18	.0440	4,890	6,340,000	.0067	.0251	.0253	.0180	.0672	.0677	....	2.676	....	166.7
		Av.	....	....	....	....	....	3,680	5,440,000	.0076	.0253	.0255	.0187	.0681	.0683	2.856	2.679	.0620	166.9
13	Misc. 148..	1	2.03	.15	6	20	.0440	3,940	3,550,000	.0046	.0228	.0229	.0124	.0613	.0617	2.862	2.691	....	167.6
		2	2.00	.16	6	20	.0300	3,520	4,420,000	.0062	.0243	.0243	.0167	.0652	.0652	2.860	2.683	....	167.1
		3	1.93	.18	6	24	.0180	3,450	6,480,000	.0061	.0241	.0244	.0163	.0640	.0648	....	2.658	....	165.6
		Av.	....	....	....	....	....	3,640	4,820,000	.0056	.0237	.0239	.0151	.0635	.0639	2.861	2.677	.0643	166.8

NOTE.—Specific gravities corrected at 70° F.

Chemical analyses of slate samples.

	1.	2.	3.	4.	5.	6.	7.	8, 10, 13.	9.	11.
Silica	53.81	54.83	68.90	57.79	69.76	52.50	55.71	53.23	52.35	52.79
Alumina	25.40	23.53	14.03	22.92	14.16	26.31	25.20	26.29	26.16	24.96
Ferric oxide	6.17	5.06	(a)	5.19	(a)	3.98	2.46	3.81	5.81	6.27
Manganese oxide	.06	.14	.02	.07	.04	.11	.11	.06	.10	.06
Lime	.31	.28	.37	.23	.38	.28	.26	.31	.29	.28
Magnesia	1.74	3.05	1.11	1.97	1.32	2.27	1.74	1.87	2.29	1.69
Sulphuric anhydride	Tr.	.26	.56	.08	.07	.22	Tr.	Tr.	Tr.	Tr.
Ferrous oxide	2.75	3.41	4.65	2.62	4.58	5.34	3.97	4.21	3.16	3.81
Sodium oxide	.49	.21	.05	.12	.13	.04	.22	Tr.	.16	.03
Potassium oxide	4.27	3.21	2.14	4.66	1.94	3.32	4.51	3.58	3.82	3.52
Water at 100° C	.66	.43	.66	.48	.54	.47	.53	.59	.57	.72
Ignition loss	4.62	6.01	7.69	4.13	7.44	5.33	5.13	5.82	5.19	5.79
	100.28	100.42	100.18	100.26	100.36	100.17	99.84	99.77	99.90	99.92

[a] Owing to the large amount of volatile organic material it is impossible to determine the ferrous oxide, consequently all iron has been assumed as being present in the lowest state and calculated as such.

THE OOLITIC LIMESTONE INDUSTRY AT BEDFORD AND BLOOMINGTON, INDIANA.[a]

By Jon A. Udden.

LOCATION AND AREA.

The building stone here considered is known by different trade names, as "Bedford stone," "Bedford oolitic limestone," "Indiana limestone," and "Indiana oolitic limestone." It is used extensively in the construction of government, municipal, and private buildings. It is quarried in south-central Indiana, principally in Lawrence, Monroe, and Owen counties. The two most active centers of stone production are Bedford, in Lawrence County, and Bloomington, in Monroe County. These counties are considered to be in the heart of the building-stone region, which in this vicinity averages in width about 3 miles east and west; but the stone is more widely distributed, extending nearly 150 miles north and south from Parkersburg, in the southern part of Montgomery County, to Ohio River, and from 2 to 14 miles east and west.

The pioneers in developing the building-stone industry were Davis Harrison and Nathaniel Hall, who opened the Blue Hole quarry, about 1 mile east of Bedford, toward the close of the fifties. Since then the number of openings has increased so that at the present time about 125 sites may be observed of quarries that are either in actual operation or have been abandoned.

GEOLOGY.

The geology of this region is rather simple. The rocks comprise unconsolidated deposits of Quaternary age and hard rocks of Mississippian age. The Quaternary deposits consist of glacial till and drift,

[a] For discussions of the geology of the oolitic limestone in Indiana the reader is referred to the following papers by Hopkins and Siebenthal and Ashley, and for greater detail regarding some of the quarries to the paper by Blatchley.

Hopkins, T. C., and Siebenthal, C. E., The Bedford oolitic limestone: Twenty-first Ann. Rept. Indiana Dept. Geology and Nat. Res., 1896, pp. 291–427.

Ashley, G. H., Geology of the lower Carboniferous area in southern Indiana: Twenty-seventh Ann. Rept. Indiana Dept. Geology and Nat. Res., 1903, pp. 49–122.

Blatchley, R. S., The Indiana oolitic limestone industry in 1907: Thirty-second Ann. Rept. Indiana Dept. Geology and Nat. Res., 1908, pp. 301–459.

lacustrine and terrace deposits, and alluvial flood plains. The hard rocks of Mississippian age that outcrop in Lawrence, Monroe, and Owen counties consist of the following, named in the order of age:

Chester group.
Mitchell limestone.
Spergen limestone (known to the trade as Bedford limestone).
Harrodsburg limestone.
"Knobstone" group.

The contacts between these formations as observed in this region are very sharp. The contact between the Spergen limestone (Bedford oolitic stone) and the Mitchell limestone is particularly sharp.

In a geologic sense the name "Bedford" limestone has been replaced by Spergen limestone, because of the conflict of the name Bedford with the well-established term Bedford shale of the Carboniferous of Ohio.

The rocks in this region have a general dip to the southwest, amounting to 50 or 60 feet to the mile; there are no other notable structural features. The physiographic features in this area are in part controlled by the dip of the strata, which has aided in the initial direction of the drainage, and in part by the resisting or nonresisting character of the various formations to erosion and disintegration, which has given rise to various topographic features, such as knobs, ridges, wide and narrow valleys, sink holes, and subterranean drainage.

The most interesting formations are the Spergen and Mitchell limestones. All the stone used as a building stone is obtained from the Spergen and crushed stone is supplied by the Mitchell, which in many places has to be removed before the building stone can be obtained. The Spergen (Bedford oolitic) limestone outcrops in nearly all the stream valleys, and the outcrops vary in thickness from 25 to 100 feet. It is because of this physiographic feature that nearly all the quarries are located in or adjacent to the valleys. Another factor that has aided in the location of quarries is the thickness of the overlying Mitchell limestone. Where erosion and disintegration have continued a long time a great deal of the overlying Mitchell limestone has been removed, and at these places the early quarries were located. At present a great number of these quarries have exhausted their easily accessible supply of stone, and now in order to carry on operations it has become necessary to remove from 30 to 40 feet of the Mitchell limestone.

ECONOMIC DATA.

QUARRIES.

Two steps are necessary in preparation of the stone for construction work—first, the quarrying of the stone; second, the milling of the raw material. Two concerns therefore handle the stone, the quarry company and the stone-mill company. Some of these concerns are independent of one another, but most of them are closely associated.

The whole region has been subdivided into districts, partly according to the quality of the stone, partly to the prominence of the locality, and partly to the quantity of the stone produced. There are in all 14 districts, situated as follows: In Lawrence County, Peerless, Buff Ridge, Reed Station, Dark Hollow, Spider Creek, Bedford, and Rock Lick districts; in Monroe County, Stinesville, Elletsville, Hunter Valley, Bloomington, Sanders, and Belt or Clear Creek districts; in Owen County, Romona district.

The quarries differ greatly in size; the largest in operation at present are in the Buff Ridge, Clear Creek, and Romona districts. The largest quarries in the Buff Ridge district are operated by the Perry-Mathews-Buskirk Stone Company and the Bedford Quarries Company; in the Clear Creek district, by the National Stone Company, the Chicago-Bloomington Stone Company, and the Monroe County Stone Company; in the Romona district, by the Romona Oolitic Stone Company. The first two districts were visited, and a description of one of the largest quarries will serve as an illustration of the character and equipments of quarries in this region.

This quarry is situated in the Buff Ridge district, on a tract of 160 acres of land, 80 acres of which contains good building stone. Up to the present about 40 acres of this has been quarried by several openings more or less separated from one another.

Over a greater portion of this quarry a considerable amount of stripping is necessary, consisting of clay up to 5 feet thick and limestone. This is especially true of the west and north workings, where as much as 35 feet of Mitchell limestone has to be removed. Most of this is quarried by drilling and blasting and removed by a steam shovel, then loaded into cars or dumped into old workings. The clayey material is generally removed by means of scrapers.

After the overburden has been removed the stone is ready to be quarried. The thickness of the stone suitable for a first-class building material ranges from 45 to 70 feet, though stone 70 feet thick is uncommon. The greater part of this consists of a buff-colored stone, but in the lower portions of the quarry the blue stone predominates.

The equipment for quarrying the stone at this place consists of 45 channeling machines of the Sullivan, Ingersol, Wardwell, and New Albany types, and 25 derricks. Some of the derricks are operated by steam and some by hand. Generally a derrick is so placed that it will handle the stone obtained from an area about 125 feet square, and two or three channeling machines are used in the same area.

The stone, after it has been channeled, loosened, and cut into desired lengths, is hoisted from the pits and placed on flat cars, a part of the stone being shipped directly to the mill and a part retained in order to be reduced to a uniform size at the quarry by a machine known as a scabbling machine. The function of this machine is to reduce the stone to somewhat even blocks, in order to lower the cost of shipment of quarry blocks to distant points. The machine consists of a set of cast-steel gearing, so arranged as to revolve two heavy disks in opposite directions and also to move a traveling table or platen beneath them. The disks are 2 inches thick and 3 feet in diameter. They are perforated so as to permit the introduction of pointed steel teeth, three on each disk, so set that those of one disk correspond to those of the other. The first pair are 1 inch shorter than the following pair. The third pair are 2 inches longer than the second pair. Thus on one revolution stone to a depth of 3 inches is cut from the block. The last pair of teeth are finishers.

The cutting of these teeth by a circular motion gives the block face a grilled surface. The disks revolve always one way, the teeth on one disk operating downward at the top of the block and the teeth in the opposite disk acting upward at the bottom of the block.

The machinery used at the quarries does not vary a great deal and is less complicated than the machinery used in the stone mills. In the process of stripping the equipment depends greatly upon the nature of the material to be removed—whether it is clay or stone. Where there is an abundance of clay it may be removed by either a wet process (hydraulicking) or a dry process (by means of scrapers). Where there is an abundance of limestone in the overburden it is necessary to use steam drills and powder. The material after it has been blasted out is removed either by steam shovels or by hauling in wagons.

In quarrying the building stone either single or double acting channeling machines of the following types are used: Wardwell, Ingersol, New Albany, and Sullivan. The Wardwell machine is used more extensively than any other, principally because it was the first machine to be used in the stone region. The stone is quarried in blocks 30 to 40 feet long, 8 to 10 feet wide, and 6 to 10 feet thick. In order to reduce these larger blocks, small steam drills of the Ingersol "Baby Giant" type are used in many quarries. Hoisting derricks are in part constructed of wood, but recently steel derricks have been introduced. The derricks are operated either by steam, by electricity, or by hand. Where steam is used, three or four derricks are usually operated by one man.

In some of the pits where no natural drainage is to be had pumps are kept in operation to remove the surface water.

MILLS.

At Bedford there are 16 mills engaged in producing finished Bedford oolitic limestone. The largest stone mills in operation are those of the Furst-Kerber Cut Stone Company and the Bedford Quarries Company. Most of the mills purchase rough stone either from the Perry-Mathews-Buskirk Stone Company or from the Bedford Quarries Company. Some of the mills operate their own quarries, but during the past year these have been idle, because rough stone could be purchased from the Perry-Mathews-Buskirk Stone Company and the Bedford Quarries Company at a lower price than the cost at the other quarries.

The various mills in operation at Bedford are the following: (1) Furst-Kerber Cut Stone Company, general offices, 443 Fifth avenue, Chicago, Ill.; (2) J. P. Falt Company, general offices, Springfield, Ohio; (3) Bedford Cut Stone Company, Bedford, Ind.; (4) Climax Stone Company, Bedford, Ind.; (5) John A. Rowe Cut Stone Company, Bedford, Ind.; (6) Indiana Cut Stone Company; (7) Ingalls Cut Stone Company, general offices, Binghamton, N. Y.; (8) Hann Mill; (9) Shea & Donnelly, general offices, Lynn, Mass.; (10) Bedford Steam Stone Works, Bedford, Ind.; (11) Brook Cut Stone Company, Bedford, Ind.; (12) Perry-Mathews-Buskirk Stone Company, Chicago, Ill.; (13) Henry Struble Cut Stone Company; (14) Dugan Cut Stone Company; (15) Giberson Cut Stone Company; (16) Bedford Stone and Construction Company, Indianapolis, Ind.

At present the largest mill producing finished stone ready to be placed in a building is equipped as follows: The building, covering an area 500 feet long and 165 feet wide, is provided with modern machinery. During the winter months this building is heated by hot air and during the summer months cooled by a large fan. The building is lighted by electricity. On an average about 130 men are employed during the year. The equipment for producing a finished stone consists of the following machinery: Six steel-blade gang saws; two diamond saw machines, one a single circular saw, 74 inches in diameter, in which there are 168 diamonds, operated by belt from a shaft, and the other a double circular saw 100 inches in diameter, each saw containing 180 diamonds, operated by an individual motor; nine planers, seven of which are double platen planers, one a single platen planer, and one a circular planer; the largest planer will accommodate a stone 16 feet 8 inches by 8 feet 4 inches by 4 feet 2 inches; two headers; five lathes, the largest of which will turn out a stone 30 by 8 feet; six electric traveling cranes, of 3, 3, 5, 15, 30, and 110 ton capacity. A compressed-air machine is used for pneumatic tooling and for light drilling.

The average annual output of finished stone at this mill amounts to about 200,000 cubic feet. The greater portion of the rough stone that was bought cost, on an average, during 1909, 25 cents a cubic foot.

It is understood among local concerns that a company operating both quarry and mill and at the same time selling stone to various other companies may not produce a finished stone for building purposes. This agreement, however, does not seem to be universally observed.

At Bloomington there are five stone mills producing finished stone, located along the Illinois Central and the Chicago, Indianapolis, and Louisville railroads. The Central Oolitic Stone Company (17) is located in the northern part of Bloomington, and the South Side Stone Company (18), James H. Nolan & Sons (19), the Hoadley Cut Stone Company (20), and the Bloomington Cut Stone Company (21) are located in the southern part of Bloomington.

The equipment in the various mills depends greatly on the contracts obtainable by each individual company. The machinery used is, however, the same, and consists generally of one or more gang saws, planers, either single or double platen, circular planers, headers, lathes, diamond saws, either circular or horizontal, and pneumatic tools. To convey the stone from point to point either steam or electric traveling cranes are used, but in some places derricks serve this purpose. The machines in use in the mills at Bedford and Bloomington are summed up in the following table, in which the numbers at the top correspond to those given to the different plants in the lists above and on page 339.

Summary of equipment of stone mills at Bedford and Bloomington, Ind.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	Total.
Gang saws	1	6	2	1	...	2	3	6	8	1	21	3	2	4	6	6	6	3	....	4	2	87
Planers	6	2	2	4	9	5	6	4	4	2	5	5	3	3	8	3	3	2	2	4	2	84
Headers	1	...	...	...	2	1	...	1	1	1	1	1	1	...	...	1	1	....	....	....	2	14
Lathes	2	1	...	...	5	1	...	1	3	...	4	...	...	...	1	...	2	1	....	3	....	24
Diamond saws	1	...	1	1	2	2	1	...	1	...	1	1	1	...	3	...	1	1	1	2	1	20
Traveling cranes	3	1	1	2	6	2	3	3	3	1	5	3	2	2	5	2	1	....	1	2	....	48
Air compressors	...	...	1	1	1	1	...	...	1	...	1	1	1	...	1	...	....	....	....	1	....	10

WASTE AND ITS UTILIZATION.

During the processes involved in quarrying and in preparing the stone for its final use a large quantity of material is wasted. The waste is in part caused by peculiarities of the stone, by its handling, and in part by the designers' ideas in ornamental construction. Waste may be considered, first, as it occurs in the quarries, and, second, as it occurs in the mills.

The waste occurring in the quarries may be due to various factors, such as the quantity and the character of the overburden, the color of the stone, irregularities in the stone known as stylolites or "crow's feet," joints, the texture of the stone, and quarry practice in general.

Where there is a comparatively thick overburden to be removed there is less waste than where the overburden is thin or lacking. The tendency of the greater thickness of overburden is to protect the desired stone from the action of percolating waters, which if unchecked tend to form solution channels. The absence of these channels is noticeable particularly in some of the workings of the Perry-Mathews-Buskirk quarry, where an overburden 30 feet thick has to be removed. The effect of a thin overburden is well illustrated in the quarries of the Bedford Quarries Company and likewise in nearly all of the quarries south of Bloomington. In these quarries the surface of the Bedford oolitic stone is very irregular, because of the solvent action of surface waters; besides, there are numerous solution channels filled with clay, 3 to 4 feet wide and 10 to 12 feet deep, and even greater.

The Bedford oolitic stone is blue or buff in color; originally probably all the stone was blue. The change in the color of the stone is due in part to a chemical reaction by which ferrous compounds present in the stone are oxidized to ferric oxide, partly by oxygen present in the ground water. The line of demarcation between blue and buff is very sharp and irregular. The occurrence of the two colors in the same block of stone lessens the price, so that stone of this character is usually considered as waste.

Structural irregularities known as stylolites or "crow's feet" and "toe nails" cause considerable waste in places, perhaps as much as 3 to 5 feet on either side of the stylolite. These are, however, not abundant, and generally in a quarry not more than two are encountered in the entire thickness of the stone. Some joints cause considerable waste, especially where the overburden has been very thin, allowing surface waters to follow their course so as to form solution channels. Where these are numerous it is difficult to quarry blocks of suitable size, and moreover the color of the stone along these places is very irregular.

The texture of the Bedford oolitic stone is granular, varying from a very fine to a coarsely granular stone. When extremely fine or coarse stone is obtained it is discarded, because the former is too expensive to work and the latter can not generally be sold. In places small crystals of calcite occur in cavities or along fractures known as "glass seams," and generally stone in which these are encountered has to be rejected.

In quarrying the stone there is always a certain amount of waste due to the channeling machines, to irregularity in the breaking of blocks, to scabbling the stone either by hand or machine, and to other mechanical means used in obtaining the stone. Considering all of these various ways in which a stone may be spoiled it is estimated that in the quarries the total quantity of waste varies between

35 and 50 per cent. The great proportion of waste may be clearly appreciated by observation of the immense grout piles in and around all quarries.

In the mill the quantity of waste is not so large as in the quarries; nevertheless the percentage is comparatively high, considering that choice blocks of stone are always used. Various mill operators estimate that in the mills the waste amounts to 20 to 25 per cent The waste is principally in planer and lathe work where large columns and various trimmings for buildings are made.

Most of the stone rejected in the quarries is dumped into old workings or into large grout piles and is never used.

Practically no attempts have been made by the quarrymen themselves to use the rejected stone. At present, however, the waste is used to some extent in making lime and as a flux. At the Perry-Mathews-Buskirk Stone Company's quarry the rejected stone is being used to some extent by the Ohio Western Lime and Cement Company. In making lime the equipment for burning consists of three kilns of stone and two cylindrical steel kilns, four of these being in continual operation. About 120 barrels of lime is burned in each kiln daily. The greater part of the output is shipped to the waterworks at Cincinnati, Ohio.

The waste from the various stone mills is used by the Illinois Steel Company as a flux; the entire waste occurring in each plant is generally loaded into cars and is paid for at 15 cents a ton.

There are no crushing plants in operation at the quarries in either Bedford or Bloomington. It seems as if it should be possible to make use of the rejected stone, provided low freight rates could be had, so that crushed stone could be furnished to the surrounding towns. The Mitchell limestone, which overlies the Spergen ("Bedford") limestone, is a hard, generally fine-grained and durable stone, and it would be suitable for crushed stone. This material could no doubt be used to advantage in concrete work as well as in road construction. Besides the Mitchell limestone stripping, the rejected blocks of building stone could be used to advantage as crushed stone.

Both the Mitchell limestone and the Bedford oolitic limestone have been used in and around Bedford and Bloomington in the construction of highways, small local quarries having been opened for that purpose.

PORTLAND CEMENT MATERIALS.

The possibility of using the rejected stone in the manufacture of cement has not yet received very much consideration.

A Portland cement plant is operated by the United States Cement Company about 1½ miles southeast of the Lawrence County courthouse at Bedford, on the east side of the Baltimore and Ohio Railroad. A new quarry was opened, although stone equal to the material now being used could have been had at any of the larger quarries and with a less amount of labor. The rock used in the manufacture of the cement is Mitchell limestone. The quarry from which the limestone is obtained is situated about 900 feet east of the crusher plant. This limestone varies in thickness from 30 to 55 feet and consists of a fine to coarse grained dark-blue stone. About 15 feet above the level of the quarry floor there is a ledge of grayish shaly limestone, reported to be high in magnesium, which varies in thickness from almost nothing to 4½ feet.

Analyses of limestone obtained on the premises show the following composition:

Analyses of Mitchell limestone from Bedford, Ind.

	1.	2.		1.	2.
SiO_2	0.94	1.20	$CaCO_3$	97.28	92.20
Fe_2O_3	.54	.78	$MgCO_3$	.98	.68

The shale used in the manufacture of the cement is shipped in from pits operated by the same company at Brownstown, Ind. The cost of transporting the shale from Brownstown to Bedford amounts to 50 cents a ton. The chemical composition of this clay varies, as observed in the following analyses:

Analyses of shale from Brownstown, Ind.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	61.92	59.00	58.20	59.24	66.90	61.56	66.66
Al_2O_3	19.03	21.50	21.60	20.46	22.90	27.00	25.7
Fe_2O_3	6.33	7.01	7.60	7.18	....	....	....

The mixture at present used consists of 12,000 pounds of limestone to about 3,100 pounds of shale.

LABOR CONDITIONS AND WAGES.

In both Bedford and Bloomington there is usually a shortage of men for both the quarries and the mills. This is especially true in the quarries, where all of the work has to be carried on in the open and the working days are dependent on weather conditions. In the mills, where nearly all of the work is carried on under cover, there is less trouble in keeping men. On an average laborers in quarries receive about $1.50 a day. In the stone mills the wages range from 62½ cents down to 15 cents an hour and average about 26 cents. The carvers are the best paid and the other operatives rank somewhat in the following order: Stonecutters, plane men, blacksmiths, traveling runners, head sawyers, head hookers, tool grinders, car blockers, sawyers, hookers, assistant tool grinders, mill laborers, and wire-saw men.

SHIPPING FACILITIES AND RATES.

Both Bloomington and Bedford are favored with transportation facilities. The railroads entering this region are the Illinois Central, the Chicago, Indianapolis and Louisville, the Indiana Southern, and the Baltimore and Ohio Southwestern, besides some local lines which handle the stone between the quarries and railroads.

The freight rates in effect during 1909 are of interest as showing the consistent rates enjoyed by the Bedford stone between different parts of the United States. Freight rates on 100 pounds of stone from the Bedford district to points in Indiana range from 3 to 12 cents. The rates to points outside of Indiana range from 6 cents per hundred to Louisville, Ky., up to 64 cents per hundred to San Francisco and Seattle. The rate to Chicago is 11 cents; to Kansas City it is 21 cents; to Denver, 35 cents; to St. Paul, 18 cents; to New Orleans, 20 cents; to Atlanta, 19 cents; to New York, 28 cents; and to Boston, 30 cents.

COMMERCIAL VALUE OF BEDFORD OOLITIC STONE.

The price of stone varies considerably, especially when the color of the stone is taken into consideration. Rough quarry blocks, either buff or blue, known as A-1 stone, quarried around Bedford, sold during 1909 for 25 cents a cubic foot. The same stone in scabbled blocks sold for 30 cents a cubic foot. Buff or blue stone quarried at Bloomington sold during 1909 for 18 or 20 cents a cubic foot. There is still another grade of stone known as "mixed stone" which has both a buff and a blue color. Stone of this grade is the cheapest and sells for 8 cents a cubic foot. The price of this grade of stone is essentially the same at Bloomington and Bedford. As soon as the stone has to be put through various other processes it increases in price, and the price varies greatly, depending on the amount of work that has to be done on the stone.

The price of sawed stone is as follows at Bedford:

Price per cubic foot of sawed stone at Bedford, Ind.

	Cents.
Sawed on two sides, buff or blue stone	35
Sawed on four sides, buff or blue stone	50
Sawed on two sides, mixed stone	15
Sawed on four sides, mixed stone	23

The prices on stone at Bloomington when sawed are usually 10 to 15 cents a cubic foot less than at Bedford. This difference is due to the fact that the rough stone can be had at a lower price than at Bedford. The greatest cost pertains to stone on which there is a great deal of fancy carving or on which considerable planer or lathe work has to be undertaken.

COMPARATIVE STATISTICS OF STONE PRODUCTION.

During the last ten years the total value of all building stone produced in the United States amounted to $49,270,771. The total value of all the building stone produced during this time in Indiana amounted to $20,912,028 and in Missouri to $4,691,047. The combined value of the stone produced in Indiana and Missouri amounted to $25,603,075, or approximately 51.96 per cent of the total value of the stone produced in the United States. During this time approximately 42.44 per cent of the total value was produced in Indiana and 9.52 per cent in Missouri. In the following table is given the value of all building stone produced in the United States, in Indiana, and in Missouri during each of the last ten years:

Value of building-stone production in the United States, Indiana, and Missouri.

Year.	United States.	Indiana.	Missouri.
1899	$5,075,158	$1,400,854	$242,469
1900	4,330,706	1,639,985	362,344
1901	5,219,310	2,123,237	377,146
1902	5,563,034	1,813,577	429,115
1903	4,981,241	1,880,561	447,884
1904	4,543,760	2,059,386	410,918
1905	5,312,183	2,492,960	580,835
1906	5,098,631	2,636,421	690,625
1907	4,580,226	2,378,008	538,114
1908	4,566,522	2,487,039	603,597
	49,270,771	20,912,028	4,691,047

SUPPLEMENTARY NOTES ON THE GRANITES OF NEW HAMPSHIRE.

By T. Nelson Dale.

INTRODUCTION.

The granites and granite quarries of Concord, Milford, and Redstone, N. H., were described in a former bulletin.[a] During the summer of 1909 the remaining active granite quarries of New Hampshire were visited as well as a few idle ones. The results of these observations and studies are here given. The treatment of the subject, as in Bulletins 313, 354, and 404, on the other New England granites, is both scientific and economic.

The words "coarse," "medium," and "fine," as applied to granite, are to be understood as in those bulletins: *Coarse*, with feldspars over 0.4 inch; *medium*, with those under 0.4 and over 0.2 inch; *fine*, with those under 0.2 inch.

As in the bulletins referred to, the number of each specimen described, to which that of one or more thin sections corresponds, is given so that the descriptions can be verified by consulting the collections at the National Museum.

All the granites here described, as well as the other New Hampshire granites described in Bulletin 354, will be found commercially classified and scientifically determined in the table on pages 370–371, which is thus complete for this State. The total number of quarries is 49.

The local or trade names of the granites have no geologic significance.

Dr. Albert Johannsen, of the United States Geological Survey, has critically revised the more difficult petrographic determinations.

LOCATION OF THE QUARRIES.

The quarries are in the towns of Fitzwilliam, Marlboro, and Troy, in Cheshire County; Kilkenny and Stark, in Coos County; Canaan, Haverhill, and Lebanon, in Grafton County; Brookline, Manchester, and Nashua, in Hillsboro County; Allenstown and Hooksett, in Merrimack County; Rochester, in Strafford County; and Sunapee, in Sullivan County.

[a] Dale, T. Nelson, The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: Bull. U. S. Geol. Survey No. 354, 1908; New Hampshire, pp. 144–188.

GENERAL PETROGRAPHIC CHARACTER OF THE GRANITES.

The granites of these quarries fall into nine petrographic groups:

Fine quartz monzonite (Brookline).

Coarse biotite granite gneiss (Canaan and Lebanon).

Medium-grained gray biotite granite (Manchester and Rochester).

Medium-grained pinkish biotite granite (Stark).

Fine bluish-gray granites with both muscovite and biotite in varying proportions, exceptionally with porphyritic texture (Troy, Marlboro, Fitzwilliam, Sunapee).

Fine biotite-muscovite granite (gray or pinkish) with sparse large porphyritic feldspars (Briar Hill, Haverhill).

Medium-grained muscovite-biotite granite (Allenstown and Hooksett).

Muscovite-biotite gray granite gneiss (Nashua).

Augite-biotite granite, olive-green on exposure (Kilkenny).

GEOLOGIC OBSERVATIONS AT THE QUARRIES.

INCLUSIONS AND CONTACTS.

On the east side of the Perry quarry near Lake Sunapee (pp. 368–369) are two inclusions of quartz-mica diorite gneiss. The larger, 10 feet long and of very irregular outline, is crossed by meandering quartz veins. These inclusions appear to lie not within the fine granite of the quarry but within a coarser granitic rock adjoining or crossing it. The diorite consists of andesine, biotite, quartz, and titanite. Back of the northeast corner of the quarry is another inclusion of a similar rock, but with some hornblende. These diorites resemble that described in Bulletin 354, page 187. A disused quarry of that rock occurs a little north of the Perry light-granite quarry. A coarse porphyritic granite occurs also on the same hillock. A little west of Sunapee on the road to Newport a coarse porphyritic granite, a fine-grained granite, and a dark schistose rock all occur in a single outcrop. The relations of the diorite gneiss to the fine and the coarse granite were not further investigated.

The quartz monzonite at the O'Rourke quarry in Brookline (p. 361) contains inclusions up to 6 by 3 feet of quartz-mica diorite gneiss, consisting of quartz, biotite, and oligoclase-andesine to andesine.

The quartz monzonite at the Fessenden quarry at South Brookline (p. 362), which lies a mile south-southwest of the O'Rourke quarry, contains inclusions of coarse banded biotite gneiss (with lenticular feldspars) up to 20 by 9 inches. The chief feldspar is orthoclase with a little microcline; the other is oligoclase. The size and number of the inclusions at a disused opening here points to the proximity of the gneiss capping.

The biotite granite of the Bodwell and Kennard Ledge quarries at Manchester (pp. 363–364) appears as narrow dikes intruding a quartz-mica diorite gneiss varying much in texture and crossed by pegmatite dikes. At the Kennard ledge quarry the dike strikes north but the gneiss foliation nearly east. At the Bodwell quarry there are tongues and inclusions of this gneiss in the granite.

DISCOLORED GRANITE ADJACENT TO BASIC DIKE.

The light-gray muscovite-biotite granite at the Bailey quarry in Allenstown (pp. 365–366) is crossed by a hornblende diabase dike 3 to 4 feet thick. The granite for 14 feet on one side and 2 feet on the other has become medium greenish gray owing to the slight chloritization of its plagioclase.

PEGMATITE DIKES.

The pegmatite dikes at the Bailey quarry, referred to above, contain black tourmaline and beryl. A thick dike of coarse garnetiferous pegmatite in the center of the Marlboro quarry has a border made up largely of beryl and its biotite is in blades a foot long and 1 inch wide. This dike is reported to have yielded a garnet crystal over 6 inches in diameter and beryls of the same length. The pegmatite dikes of the Perry Sunapee quarry contain the usual black tourmaline and garnets.

THE GRANITES AND QUARRIES.

The granite and quarry descriptions are arranged alphabetically by counties and townships.

CHESHIRE COUNTY.

WEBB FITZWILLIAM QUARRY.

The Webb Fitzwilliam quarry is one-half mile south of Fitzwilliam Depot, in Fitzwilliam Township. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, Webb Granite and Construction Company, 40 Crescent street, Worcester, Mass.

The granite (specimen D, XXX, 66, a), "Fitzwilliam Webb," is a muscovite-biotite granite of light, very bluish gray color and of even-grained fine texture, with feldspars and micas under 0.2 inch. Its constituents, in descending order of abundance, are: Clear bluish to translucent potash feldspar (microcline and orthoclase), slightly kaolinized; clear colorless quartz with cavities and hairlike crystals of rutile; clear to milk-white soda-lime feldspar (oligoclase), some of it slightly kaolinized and micacized; muscovite (white mica) in large scales; and biotite (black mica) in more abundant and much smaller scales. Accessory: Magnetite (very little), apatite, rutile. Secondary: Kaolin, a white mica. No effervescence with cold dilute muriatic acid.

The quarry, opened before 1829, measures about 1,300 feet in a N. 50° E. direction by 200 feet in width for half of its length and by 250 feet for the rest, and from 6 to 35 feet in depth. The stripping consists of 18 inches of loam.

The sheets are 6 inches thick at the top and 3 feet at the bottom, the greater part, however, being thin ones. They dip 15° NW. at the northwest side but turn, dipping northeast on the northeast side of the hill. The general structure of the hill is thus that of either a dome or an anticline. There are only five joints. Set (*a*) of four joints, near the northeast end of the quarry, strikes N. 20° W., dips 90° or steep east or west, and is spaced 5, 20, and 100 feet. The (*b*) joint, near the southwest end of the quarry, strikes N. 40° E. and dips 70° N. 50° W. The rift is reported as striking N. 55° E. and dipping 35°–40° N. 35° W., and the grain as dipping 80° S. 35° E. In working the rock is split along the grain. Many dikes of garnetiferous pegmatite, from an inch to 2 feet thick, strike north or north-northwest and dip 90° or 20° E. In places the pegmatite is associated with aplite. Small aplite dikes, 1 to 2 feet apart, strike east. All these dikes throw considerable stone into the second class. No rusty stain nor segregations were observed.

The plant comprises three derricks (30 and 40 ton), three hoisting engines, a 10-ton traveling crane, an air compressor (capacity 700 cubic feet of air per minute), three large rock drills, 12 air-plug drills, and a steam pump.

Transportation is effected by a 7,000-foot siding to Fitzwilliam Depot, besides 1,500 feet of subsidiary siding in the quarry.

The product is used mainly for buildings and monuments. Specimens: City hall, Newark, N. J.; approaches and base of First Church of Christ, Scientist, Boston. The smaller sheets are used for paving.

SILVER WHITE QUARRY.

The Silver White quarry is one-fourth mile northeast of Fitzwilliam Depot, in Fitzwilliam Township. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, Perry White Granite Company, Keene, N. H.

The granite (specimens D, XXX, 68, a, b), "Silver White," is a biotite-muscovite granite of light bluish-gray color and of even-grained, very fine texture with feldspars under 0.1 inch and micas to about 0.05 inch. Its constituents, in descending order of abundance, are: Clear bluish to translucent potash feldspar (orthoclase and microcline); very light smoky quartz with cavities and hairlike crystals of rutile; clear to milk-white soda-lime feldspar (oligoclase), very little kaolinized, some small mica crystals; biotite (black mica);

muscovite (white mica). Accessory: Rutile. Secondary: Kaolin, calcite. Effervesces slightly with muriatic acid test. Polished face shows neither pyrite nor magnetite.

An estimate of the mineral percentages by the application of the Rosiwal method to a camera lucida drawing of a thin section enlarged 40 diameters yields these results with a mesh of 1.8 and a total linear length of 43.2 inches:

Estimated mineral percentages in Fitzwilliam granite from the Silver White quarry.

Quartz		43.66
Potash feldspar (microcline and orthoclase)	32.22	
Soda-lime feldspar (oligoclase)	13.52	45.74
Black mica (biotite)	5.88	
White mica (muscovite)	4.72	10.60
		100.00

The average diameter of the particles, obtained from the same calculation, is 0.00668 inch.

Prof. Leonard P. Kinnicutt, of the Worcester Polytechnic Institute, by a test made December 11, 1908, for the Norcross Brothers Company in Worcester, found that 100 pounds of Fitzwilliam granite quarried by the Perry White Granite Company at this or the Snow Flake quarry absorbed 0.382 pound of water.

This is a delicate bluish-gray fine-grained stone, well adapted for fine work. Its particles are so fine and its minerals so evenly distributed that aside from a fine mottling, visible only near by, its color is uniform. It takes a good polish.

The quarry, opened about 1904, is about 300 feet square and 40 feet deep. The stripping is 10 feet thick and mostly of weathered granite.

The sheets consist of short lenses at the surface, but are not well marked below. The quarry is probably near the lower limit of sheet structure. There are no joints, but here and there a fracture crosses one sheet only. One such fracture strikes N. 40° E. and dips 60° N. 50° W. The rift is reported as horizontal and the grain as vertical, with a nearly east-west course. Pegmatite dikes up to 1 foot thick strike N. 30° W. and N. 60° W. with steep dips. Biotitic segregations are rare and up to 4 inches across. There is little or no rusty stain on sheet surfaces.

The plant of this combined with that of the Snow Flake quarry of the same firm comprises two 15-ton and two 40-ton derricks, four hoisting engines, two air compressors (capacity 1,500 and 525 feet of air per minute), three large rock drills, a hollow steel deep-hole drill (1½ inches by 6 feet), besides the following at the cutting shed: A 10-ton and a 5-ton derrick, three surfacers, and twenty air hand tools.

Transportation is by siding to Fitzwilliam Depot.

The product is used for buildings and monuments. Specimens: Smith mausoleum, Paducah, Ky.; Tanner mausoleum, Springfield, Ill.; Heywood Brothers building, Gardner, Mass. Certain buildings are enumerated below under the product of the Snow Flake quarry as built partly of the granite of this quarry.

SNOW FLAKE QUARRY.

The Snow Flake quarry is two-fifths of a mile northeast of Fitzwilliam Depot and three-fourths of a mile south of Fitzwilliam village, in Fitzwilliam Township. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, Perry White Granite Company, Keene, N. H.

The granite (specimen D, XXX, 67, a), "Snow Flake," is a biotite-muscovite granite of light inclining to medium gray shade and of porphyritic texture, with fine matrix (micas under 0.1 inch) and feldspars to 0.5 inch. Its constituents, in descending order of abundance, are: Faintly greenish clear potash feldspar (microcline in twins with crush borders, also orthoclase), some of the microcline intergrown with quartz, some slightly kaolinized; light smoky quartz with cavities, generally in sheets, and hairlike crystals of rutile; clear to milk-white soda-lime feldspar (oligoclase-albite), some of it minutely intergrown with quartz (vermicular structure), some of it a little kaolinized; biotite (black mica); and muscovite (white mica). Accessory: Apatite, zircon, rutile. Secondary: Kaolin, limonite from biotite. No effervescence with muriatic acid test.

The fineness of the mica deprives the stone of strong contrasts and the porphyritic texture is discernible only on close inspection.

The quarry, opened between 1885 and 1887, is about 300 feet square and 40 to 70 feet deep. The stripping consists of 3 to 10 feet of clay and bowlders.

The sheets, 10 to 20 feet thick, are about horizontal but irregular. There is but one joint. The rift is reported as horizontal and the grain as vertical, with about east-west course.

The plant has been described with that of the preceding quarry.

Transportation is by siding to Fitzwilliam Depot.

The product is used for buildings and monuments. Specimen: Flagstaff monument, class of 1878, Lehigh University, South Bethlehem, Pa. The following are of the combined product of this and the Silver White quarry: Art museum, Toledo, Ohio; law building of University of Iowa, Iowa City; post-offices at Muskegon, Mich., Chippewa Falls, Wis., Grand Island, Nebr., Decatur, Ill., Bedford, Ind., Mayfield, Ky., Devils Lake, N. Dak., Allentown, Pa., and Ithaca, N. Y.; and Wysong residence, corner Seventy-sixth street and Fifth avenue, New York.

HOLMAN QUARRY.

The Holman quarry is 1½ miles southeast of Fitzwilliam village and as far east-northeast of Fitzwilliam Depot. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, E. B. Holman, Fitzwilliam Depot, N. H.

The granite (specimen D, XXX, 71, a), "Fitzwilliam," is a muscovite-biotite granite of light bluish-gray color and of even-grained medium inclining to fine texture, with feldspars under 0.3 inch and mica under 0.1 inch. Its constituents, in descending order of abundance, are: Clear bluish potash feldspar (microcline and orthoclase) intergrown with quartz, circular in cross section; clear, colorless quartz with cavities, some in sheets, and hairlike crystals of rutile; milky soda-lime feldspar (oligoclase), some of it kaolinized and micacized; muscovite (white mica); biotite (black mica). Accessory: Magnetite (very little), apatite, rutile. Secondary: Kaolin, a white mica, calcite. The stone effervesces slightly with muriatic acid test.

The quarry, opened in 1909, is about 20 feet square and 12 feet deep. The stripping consists of 2 feet of clay and bowlders.

The sheets, insufficiently exposed, are probably up to 10 feet thick. One joint and heading on the south side strikes N. 80 W., vertical. The rift is reported as horizontal and the grain as vertical, with east-west course. There are two half-inch pegmatite dikes. Discoloration is 2 inches thick on sheet surfaces.

The plant consists of one horse derrick.

Transportation is by cartage of 1¼ miles to siding of Boston and Maine Railroad.

The product thus far has been used for local monuments.

MARLBORO QUARRY.

The Marlboro quarry is 1¼ miles north-northeast of Webb station (Marlboro Depot), in Marlboro Township. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, Webb Granite and Construction Company, 40 Crescent street, Worcester, Mass.

The granite (specimen D, XXX, 69, a), "Marlboro," is a biotite-muscovite granite of light inclining to medium, very bluish gray color, and of even-grained fine texture, with feldspars and micas to 0.2 inch. Its constituents, in descending order of abundance, are: Clear bluish to translucent potash feldspar (microcline), intergrown with quartz, circular in cross section and slightly kaolinized; clear, colorless quartz with cavities in sheets and hairlike crystals of rutile; milk-white soda-lime feldspar (oligoclase), some whatkaolinized and with small plates of muscovite; biotite (black mica); muscovite (white mica). Accessory: Apatite, zircon, rutile. Secondary: Kaolin, calcite. The stone effervesces with muriatic acid test.

The quarry, opened before 1849, was originally about 950 feet long by about 700 feet wide but now measures about 750 feet in a north-northeast direction by 200 feet across and averages 50 feet in depth.

The sheets, 6 inches to 6 feet thick, but not over 2 feet in the upper half of the quarry, are normal and horizontal, but dip low north-northeast at the north end of the quarry and turn to dip low south-southwest at the south end. The thinness of the sheets and the compressive strain prevents channeling, so dynamite is used. Two vertical joints near the north end, with N. 60° E. strike, extend off and on for 50 feet. On the extreme east side a joint striking N. 50° E. and dipping 50° NW. extends only 100 feet. Flow structure is very marked on sheet surfaces at the west side. It consists of alternately more or less biotitic planes striking N. 30° E. but also curving, varying much in width and resembling a gneiss foliation. On the east side flow structure has a N. 30°–40° E. course. There is an inclusion or an irregular biotitic flowage band, 4½ feet long, 1 foot wide, and oval in cross section. The rift is reported as horizontal and the grain as vertical, with N. 22° E. course. A thick pegmatite dike crosses the center of the quarry with N. 55° W. course and dip of 30°–45° N. 35° E. There are smaller pegmatite dikes and streaks of like course in the northern half of the quarry. There is no rusty stain on sheet surfaces.

The plant comprises five derricks (20 to 50 ton), five hoisting engines, a 10-ton traveling crane, a locomotive, an air compressor (capacity 700 cubic feet of air per minute), three large rock drills, 32 plug drills, and a steam pump, besides a stone crusher with screens of 2-inch, 1½-inch, and ¾-inch meshes and a capacity of 200 tons per day.

Transportation is effected by 4 miles of siding from Webb station.

The product is used mainly for buildings, curbing, and paving. Specimens: The lower seven stories of the Marshall Field building, Chicago; First Congregational Church, Nashua; and soldiers' monument, Fitzwilliam village, N. H.

TROY QUARRY.

The Troy quarry is three-fourths of a mile east-southeast of Troy station, in Troy Township. (See map of Monadnock quadrangle, U. S. Geol. Survey.) Operator, Troy White Granite Company, Worcester, Mass.

The granite (specimen D, XXX, 70, a), "Troy white," is a muscovite-biotite granite of light inclining to medium bluish-gray color and of even-grained fine texture, with feldspars under 0.2 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear bluish potash feldspar (microcline, generally in twins, intergrown with quartz, circular in cross section, also orthoclase); clear, colorless quartz with hairlike crystals of rutile and cavities in sheets; milk-white soda-lime feldspar (oligoclase-albite), some of it minutely intergrown with quartz, generally kaolinized and a little micacized, and with calcite; muscovite (white mica); biotite (black mica), some of it chloritized. Accessory: Magnetite (very little), pyrite, apatite, rutile. Secondary: Calcite, a white mica, chlorite.

An estimate of the mineral percentages by the application of the Rosiwal method to a camera lucida drawing of a thin section, enlarged 25 diameters, yields these results with a mesh of 1 inch and a total linear length of 59 inches, from which, however, areas of mixed particles too fine for measurement and having a total linear length of 18.28 inches had to be deducted, leaving as the total length of measured particles 40.72 inches:

Estimated mineral percentages in Troy granite.

Quartz		44.94
Potash feldspar (microline and orthoclase)	31.23	44.29
Soda-lime feldspar (oligoclase-albite)	13.06	
White mica (muscovite)	8.25	10.77
Black mica (biotite)	2.52	
		100.00

The following analysis, made for the operators by Prof. L. P. Kinnicutt, of the Worcester Polytechnic Institute, in 1891, is given here for reference:

Analysis of Troy white granite.

SiO_2 (silica)	73.15
Al_2O_3 (alumina)	17.04
CaO (lime)	.81
MgO (magnesia)	.30
K_2O (potash)	5.74
Na_2O (soda)	2.05
Loss and undetermined	.91
	100.00

Professor Kinnicutt, by a test made for the operators December 11, 1908, found that 100 pounds of this granite absorbs 0.269 pound of water, as compared with 0.371 pound for the same weight of Concord granite and 0.420 pound for 100 pounds of quartz monzonite from the New Westerly quarry at Milford, N. H.[a]

The following compression test on a 6-inch cube was made at the United States arsenal at Watertown, Mass., on April 15, 1891 (No. 7419): First crack at 525,000 pounds, total pounds 630,100. Ultimate strength per square inch, 17,950 pounds.

[a] See Bull. U. S. Geol. Survey No. 354, 1908, pp. 173, 174.

This stone is harder than many granites. It lends itself well to fine carving, as is shown by the garland of roses so finely executed by Joseph Carabelli, of New York, on the Hawgood monument at Lake View Cemetery, Cleveland, Ohio.

The quarry, opened about 1859, measures about 300 feet in a N. 15° E. direction by 180 feet across and from 50 to 70 feet in depth. The stripping consists of 15 feet of clay and loam.

The sheets, 6 inches to 15 feet thick, dip 10°–15° W. There are two sets of joints—(*a*), striking N. 77° W., dipping 65° S. 13° W.; (*b*), striking about north, one only, on the east wall. The rift is reported as horizontal and the grain as vertical with N. 15° E. course. There are biotitic segregations up to 2 inches in diameter. Rusty stain is generally absent, but one sheet surface showed 6 inches of it. An east-west compressive strain is noticeable.

In quarrying channeling is done on two sides along the grain, and powder or wedges are used along the hardway.

The plant comprises four derricks of 8, 10, 25, and 50 tons, five hoisting engines, an air compressor (capacity 100 cubic feet of air per minute) run by a 20-horsepower engine, four large steam drills, five air-plug drills, four air hand tools, and two steam pumps.

Transportation is effected by an electric siding, 4,230 feet long, operated by a 40-horsepower gasoline engine.

The product is used about equally for buildings and monuments. Specimens: Worcester County Institution for Savings, Worcester, Mass.; Bank of Pittsburg, Pittsburg, Pa.; Howard Savings Institution, Newark, N. J.; Metropolitan Savings Bank, Baltimore; steps and approaches to Library of Congress, Washington; steps and approaches to New York Library; Hawgood monument and Mark Hanna mausoleum, Lake View Cemetery, Cleveland, Ohio; James Lister monument, Swan Point Cemetery, Providence, R. I.; Albert Wyckoff mausoleum, Woodlawn Cemetery, New York.

COOS COUNTY.

KILKENNY QUARRY.

The Kilkenny quarry is in Kilkenny Township, about 19 miles N. 28° W. from the top of Mount Washington and about 5 miles N. 79° E. from Lancaster station and 940 feet above it, on the southwest side of a ridge. The quarry has been idle for several years.

The granite (specimen D, XXX, 73, b), "Kilkenny," is an augite-biotite granite of dark olive-green color, a little lighter than the green granite of Mount Ascutney, Vt., and considerably darker than the green granite of Redstone, N. H., and Rockport, Mass.[a] It becomes lighter, that is, more yellowish brown, on continued exposure. The

[a] See Bull. U. S. Geol. Survey No. 404, 1909, pp. 116, 117, and Bull. 354, 1908, pp. 135, 136, 182.

polished face is a dark olive-smoke color. Its texture is even-grained medium, with feldspars to 0.3 inch and black silicate to 0.1 inch. Its constituents, in descending order of abundance, are: Medium olive-greenish potash feldspar (orthoclase), intergrown with soda-lime feldspar (probably albite) in alternating bands (microperthite), the feldspar sections almost all nearly rectangular; black (in thin section green) augite; biotite (black mica); greenish hornblende; rare grains of quartz with sheets of cavities; very little separate soda-lime feldspar (probably albite). Accessory: Magnetite, titanite, apatite. Secondary: Limonite from magnetite and biotite following the banding of feldspars. This is conspicuous in long-exposed specimens. There is no effervescence with muriatic acid test.

The olive tint, as in other green granites, is probably due to the combination of limonite with the originally bluish color of the feldspar. The stone takes a high polish, but some blocks are streaked either from flow structure or from veinlets.

The quarry (the upper and more recent of two openings) is about 50 feet square and 10 feet deep.

The sheets, 1 to 5 feet thick, dip 30° SW. Joints (*a*) strike N. 45° W., vertical, and are spaced 6 to 30 feet. Set (*b*) strikes N. 65° E., vertical or steep southwest, one only on northwest side, slickensided. Minute veins run parallel to joints (*b*), spaced 6 inches to 3 feet and more, and disfigure that part of the rock. An aplite dike, 2 inches wide, strikes east and dips 40° S. Rusty stain on sheet surfaces is not over an inch thick.

There is no plant.

The quarry road to the highway at the foot of the ridge is over one-half mile long. There is a disused lumber-railroad bed from the Boston and Maine Railroad at Lancaster, within a mile of the quarry.

Some steps on the south side of the Lancaster House in Lancaster are of this granite.

DAWSON QUARRY.

The Dawson quarry is in Stark Township, 3 to 4 miles due east of Groveton station, on a north-south ridge about 800 feet above the station. Operators, Cushing & Frizzell, Groveton, N. H.

The granite (specimens D, XXX, 74, a, e), "Stark," is a biotite granite of medium pinkish-gray color (a trifle darker than Concord granite) and of even-grained medium texture, with feldspars under 0.4 inch and micas to 0.2 inch, exceptionally 0.3 inch. Its constituents, in descending order of abundance, are: Pinkish potash feldspar (orthoclase), obscurely intergrown with plagioclase (probably oligoclase-albite) and much kaolinized; medium smoky quartz with cavities in sheets, a few in a set at right angles to the others; pinkish soda-lime feldspar (oligoclase-albite); biotite (black mica), some of it chloritized; and rarely a scale of bleached biotite or muscovite. Accessory: Magnetite, allanite, apatite. Secondary: Kaolin, a white mica, limonite, epidote, chlorite. There is no effervescence with muriatic acid test.

An estimate of the mineral percentages by the Rosiwal method yields these results with a mesh of 0.3 inch and a total linear length of 66.4 inches:

Estimated mineral percentages in Stark granite.

Feldspar	70.14
Quartz	27.15
Mica	2.71
	100.00

This is a constructional granite of dull pinkish color and feeble contrast, which, however, may become stronger as the quarry deepens.

The quarry, opened before 1897, measures about 50 by 30 feet and 8 to 20 feet in depth. The stripping consists of 1 to 3 feet of sand, loam, and small bowlders.

The sheets, from 6 inches to 3 feet thick, are horizontal. One set of vertical joints strikes N. 80° W. and is spaced 20 feet. There are traces of a north-south set. A few discontinuous ones strike N. 50° E. There are fine-grained light-gray and also black segregations, some of the latter with biotite and quartz particles inclosed in whitish lenses.

The plant consists of a hand derrick.

The quarry is operated only in winter, on account of the economy of sledding the stone to Groveton rather than carting it over bad roads.

The product is used for trimmings. Specimens: Trimmings of court-house, Berlin, N. H., and of several buildings in Lancaster, and a monument in the cemetery at Groveton, N. H.

The firm has also opened another quarry in the same stone about a mile north of this one, in Stark. It is near the Grand Trunk Railway and thus has better shipping facilities.

GRAFTON COUNTY.

MASCOMA QUARRY.

The Mascoma quarry is on the top of a knoll 1½ miles north-northeast of Enfield station, in Canaan Township. Operator, Norcross Brothers Company, Worcester, Mass.

The granite (specimens D, XXX, 77, a, b, c), "Mascoma," is a biotite granite gneiss of light buff-gray color speckled with black, and of even-grained, somewhat gneissoid coarse texture, with feldspars to 0.7 inch and mica aggregates to 0.4 inch. Its constituents, in descending order of abundance, are: Very light buff-gray (almost cream-colored) potash feldspar (microcline and orthoclase), slightly kaolinized; light smoky quartz, coarsely granulated, with cavities in sheets and cracks parallel thereto; milk-white soda-lime feldspar (oligoclase), much intergrown with quartz minutely circular in cross section, generally kaolinized and micacized; biotite (black mica), some of it chloritized; and very little muscovite or bleached biotite. Accessory: Magnetite, titanite, apatite, zircon. Secondary: Kaolin, a white mica, chlorite, calcite, rare limonite stain, and probably hematite. It effervesces with muriatic acid test.

This is a constructional granite, in some respects resembling that of Milford, Mass.[a] It takes a fair polish and the polished face shows some magnetite. The contrasts are chiefly between the black mica and the other minerals.

The quarry, opened in 1907, measures about 147 by 70 feet and 5 to 25 feet in depth. The stripping averages about 18 inches.

The sheets, from 6 inches to 3 feet thick and more, are about horizontal, forming short lenses. There are three sets of joints: Set (*a*), striking N. 50° E., dipping 70° N. 40° W., is spaced 2 to 25 feet and forms a heading at the northwest corner; set (*b*), striking N. 80° W., dipping S. 10° W., is spaced 2 to 25 feet; set (*c*), striking N. 65° E., dipping 60° N. 25° W., is spaced 4 to 8 feet and more. Flow structure strikes north. In the center of the quarry is a flowage band with more pinkish feldspars. The rift is reported as horizontal and the grain as vertical, with N. 32° W. course. A pegmatite dike (smoky quartz and feldspar) up to 5 inches thick dips 20° NW. There are also lenses or veins of smoky quartz up to 4 inches thick. Biotitic knots measure up to 6 inches across. There is hardly any rusty stain along the surfaces of lower sheets, and on joint faces it is not over 2 inches thick.

The plant consists of a derrick and hoisting engine.

Transportation is by cartage 2 miles to Enfield station.

The product is used mainly for buildings. Specimens: Tercentennial commemorative monument, Jamestown, Va.; lower stories of Slater Building, Worcester, Mass.; polished base course, Agricultural National Bank, Pittsfield, Mass.; Plain Dealer Building, Cleveland, Ohio; Carnegie Institute, Pittsburg, Pa. In 1909 a contract was being filled for the Royal Bank of Canada at Winnipeg, Manitoba.

POND LEDGE QUARRIES.

The Pond Ledge quarries are on the southeast side of the domelike granite mass known as Briar Hill, about a mile from Haverhill Center and about 3 miles west of Black Mount station (North Haverhill), in Haverhill Township. Briar Hill lies about N. 60° W. of Black Mountain. Operator, Jessman Granite Company, North Haverhill, N. H.

[a] Compare Bull. U. S. Geol. Survey No. 354, 1908, p. 75.

The granite from the southwestern quarry (specimen D, XXX, 75, a), "Pond Ledge gray," is a biotite-muscovite granite of light inclining to medium gray shade, and of even-grained fine texture, but with sparse porphyritic clear feldspars to 0.4 inch and mica under 0.1 inch. Its constituents, in descending order of abundance, are: Clear, colorless potash feldspar (microcline and orthoclase); clear, colorless quartz with cavities and hairlike crystals of rutile, and granulated; milk-white soda-lime feldspar (oligoclase-albite), kaolinized, micacized, and with calcite; biotite (black mica), some of it chloritized; muscovite (white mica). Accessory: Magnetite, titanite, apatite, zircon, allanite, rutile. Secondary: Kaolin, a white mica, calcite, epidote, chlorite. The stone effervesces with the muriatic acid test.

The granite from the northeastern quarry (specimens D, XXX, 75, b, c), "Pond Ledge pink," is a biotite-muscovite granite of light pinkish-gray color and even-grained fine texture, but with sparse porphyritic feldspars to 0.3 inch and micas to 0.1 inch, rarely 0.2 inch. Its constituents are identical with those of the gray (specimen 75, a), but the secondary minerals include some hematite, which produces the pinkish tint.

This stone takes a good polish. It is said to lose some of its pinkish tint on continued exposure.

These "quarries" merely utilize the talus of Briar Hill; that is, material already quarried by glacier, frost, etc. The blocks are attacked at two points about 1,000 feet apart.

The structure above the talus is not clear. The sheets on top of the hill are said to be horizontal and to range from 6 inches to 10 feet in thickness. On the side above the talus some steep joints or sheets strike nearly with the face of the cliff and are spaced 20 feet and more. There are also gently northwestward-dipping planes, possibly headings. The two granites are reported as merging into each other, the rift as dipping gently northwest, and the "head grain" as forming an angle of 75° to 80° to it. Knots are 2 inches across. Rusty stain is an inch thick on sheets, rarely 6 to 8 inches.

The plant comprises two derricks, an air compressor (capacity 14 cubic feet of air per minute), two air hand tools, a traveling overhead crane, and a 10-horsepower gasoline engine.

Transportation is by cartage 3 miles to rail.

The product is used for monuments at Bath, Lisbon, Haverhill, and Haverhill Center cemeteries.

LEBANON QUARRY.

The Lebanon quarry is at the east foot of Quarry Hill, on the west side of and close to the Hanover-Lebanon road, 1¼ miles north of Lebanon village, in Lebanon Township. (See map of Hanover quadrangle, U. S. Geol. Survey.) There are some now disused quarries of the same granite higher up on Quarry Hill. Operator, Pigeon Hill Granite Company, Rockport, Mass.

The granite (specimens D, XXX, 76, a, b), "Lebanon pink," is an epidotic biotite granite gneiss of light, faintly pinkish and greenish gray color, speckled with greenish black, and of gneissoid coarse texture, with feldspars to 0.7 inch and mica aggregates to 0.4 inch. Its constituents, in descending order of abundance, are: Light-pinkish potash feldspar (microcline and orthoclase, some minutely intergrown with plagioclase), more or less kaolinized; clear, colorless quartz, with cavities and few hairlike crystals of rutile, finely granulated; a little greenish soda-lime feldspar (oligoclase-albite to albite), much kaolinized and epidotized; biotite (black mica), usually associated with epidote and some of it chloritized; and a little muscovite (white mica). Accessory: Magnetite, pyrite, titanite. Secondary: Epidote kaolin, calcite, a white mica, chlorite. Epidote is fifth in order of abundance. In places the feldspars are surrounded by crushed feldspars and epidote. The stone effervesces with muriatic acid test.[a]

This is a constructional granite of mixed greenish and pinkish tint and gneissoid texture, resembling in some respects the granite of Milford, Mass., and also that of Canaan, N. H.[b] The polish is poor owing to large mica aggregates. The polished face shows magnetite and pyrite.

The present quarry, hardly fully opened in 1909, is on a glaciated ledge stripped in places of 5 to 10 feet of clay. The opening measures 150 by 50 feet and up to 10 feet in depth.

The sheets, 5 to 10 feet thick, are about horizontal. There are four sets of joints. Set (*a*), striking N. 43° W., vertical or dipping steep northeast, also 35° NE., is spaced 10 to 20 feet; set (*b*), striking N. 25° E., dipping 70° S. 65° E.; set (*c*), striking N. 15° W., dipping 55° S. 75° W., is spaced 10 feet and more; set (*d*), striking N. 80° E., dipping 40° N. 10° W., faced with secondary muscovite, is spaced 9 feet and more. The rift is probably horizontal. Dikes of light-pinkish aplite up to 3½ inches thick range from the horizontal to a dip of 30° W. Light and dark segregations are up to 4 inches across. Rusty stain on sheet surfaces is slight and not over 2 inches thick.

The plant comprises one derrick and a hoisting engine at the quarry and another derrick and small hoisting engine and air compressor (capacity 300 cubic feet of air per minute) at the cutting shed.

Transportation is by cartage 1¼ miles to rail at Lebanon.

[a] A full microscopic description of this granite was given by J. P. Iddings in Bull. U. S. Geol. Survey No. 150, 1898, p. 353. He regarded the epidote as mostly primary. (See in this connection Butler, B. S., Pyrogenetic epidote: Am. Jour. Sci., 4th ser., vol. 28, July, 1909, pp. 27-32.)

This gneissoid granite belongs in an area designated as protogene in Prof. C. H. Hitchcock's Geology of the Hanover, N. H., quadrangle. See Rept. State Geologist Vermont, vol 6, 1907-8, Pl. XXV (a) and pp. 165, 166.

[b] See Bull. U. S. Geol. Survey No. 354, 1908, p. 75, also this bulletin, p. 98.

The product is used for buildings. Specimens of the same granite but largely from now disused openings are the following: India Building, Boston; two stories (polished) of the New York Mutual Life Insurance Building on Chestnut street, Philadelphia; two stories of the Borden Building on Hudson street, New York. The stone has also been used to some extent in the chapel, hospital, and Butterfield Memorial buildings of Dartmouth College, at Hanover, N. H.

HILLSBORO COUNTY.

O'ROURKE QUARRY.

The O'Rourke quarry is at the east end of Brookline village, in Brookline Township. (See map of Groton quadrangle, U. S. Geol. Survey.) Operator, O'Rourke & Magner Granite Company, Brookline, N. H., also 78 North street, Salem, Mass.

The granite (specimen D, XXX, 87 a), "Brookline," is a quartz monzonite of medium buff-gray color and of even-grained fine texture, with feldspars and micas under 0.2 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with cavities; cream-colored soda-lime feldspar (oligoclase), kaolinized and micacized; clear to translucent whitish potash feldspar (microcline and orthoclase), intergrown with quartz, circular in cross section; biotite (black mica), some of it chloritized; and a little muscovite or bleached biotite. Accessory: Magnetite, apatite, zircon. Secondary: Kaolin, a white mica, calcite, chlorite. There is no effervesence with muriatic acid test.

This is a fine-grained monumental granite closely related to that of Milford, in the same county.[a] It cuts light.

The quarry, opened in 1909 but adjacent to an opening made in 1891, is on a bare ledge measuring 200 feet in a N. 20° E. direction by 100 feet across.

The sheets, 1 to 8 feet thick, dip mostly east at low angles. There are two sets of joints. Set (*a*), striking N. 20° E., vertical, spaced 6 to 12 feet, forms a small heading on the west side; set (*b*), striking N. 80° W., vertical, is spaced 25 feet and more. The rift is reported as horizontal and the grain as vertical. Inclusions of gneiss up to 6 by 3 feet occur on the southwest side. (See p. 347.) Rusty stain is 2 inches thick on surface sheets, but there is very little on the lower ones.

The plant consists of a 15 to 20 ton horse derrick and a hand derrick.

Transportation is by cartage three-fourths of a mile to the railroad.

The product is used for monuments and trimmings. Specimens from the older opening: Simon Cottan and Philip Sheridan monuments in St. Mary's cemetery, Salem, Mass.

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[a] See Bull. U. S. Geol. Survey No. 354, 1908, pp. 159, 160.

FESSENDEN QUARRY.

The Fessenden quarry is one-eighth of a mile west of South Brookline station, in Brookline Township. (See map of Groton quadrangle, U. S. Geol. Survey.) Operator, O. D. Fessenden, South Brookline, N. H.

The granite (specimens D, XXX, 88, a, b), "Brookline," is a quartz monzonite of medium, faintly pinkish gray color, and of even-grained fine texture, with feldspars to 0.15 inch and micas to 0.1 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz with cavities and hairlike crystals of rutile; milk-white soda-lime feldspar (oligoclase), kaolinized and micacized; slightly pinkish potash feldspar (microcline and presumably orthoclase); biotite (black mica), some of it chloritized; and a little muscovite or bleached biotite. Accessory: Magnetite, apatite, zircon, allanite. Secondary: Kaolin, white micas (one in veinlets), hematite and limonite stain, chlorite, calcite. There is very slight effervescence with the muriatic acid test.

An estimate of the mineral percentages, made by applying the Rosiwal method to a camera lucida drawing of a thin section enlarged 40 diameters, yields these results with a mesh of 2 inches and a total linear length of 48 inches:

Estimated mineral percentages in Brookline quartz monzonite from Fessenden quarry.

Soda-lime feldspar (oligoclase)	38.79	61.71
Potash feldspar (microcline and orthoclase)	22.92	
Quartz		32.20
Black mica (biotite)	5.08	5.24
White mica (muscovite) or bleached biotite	.16	
Magnetite		.85
		100.00

The average diameter of the particles calculated from the same measurements proves to be 0.0097 inch.

This is a fine-grained monumental granite, related to that of Milford, in the same county.[a] Its color is warmer than that of the rock from the O'Rourke quarry (p. 361), but the granites are the same. It takes a high polish and like other quartz monzonites cuts light.

The quarry, opened in 1909, is about 80 by 50 feet and up to 8 feet deep. The stripping consists of 2 to 6 feet of loam.

The sheets, 2 to 3 feet thick, range from the horizontal to a gentle easterly dip. There are two sets of joints. Set (*a*) strikes N. 30° E., vertical, one only in center; set (*b*), striking N. 75° W., vertical or steep, is spaced 10 to 20 feet. The rift is reported as horizontal and the grain as vertical, with N. 20° E. course. There are inclusions

[a] See Bull. U. S. Geol. Survey No. 354, 1908, pp. 159, 160.

of coarse gneiss and granite to 21 inches in diameter. (See p. 347.) Rusty stain on top sheets is not over 2 inches thick.

Transportation is by cartage one-eighth of a mile to rail.

The product is used for monuments and has been shipped to Milford, Pepperell, and Claremont, N. H., to Quincy, Mass., and to Ohio and Pennsylvania.

KENNARD LEDGE QUARRY.

The Kennard Ledge quarry is 1½ miles about northeast from the city hall in Manchester. Operator, Evariste Dionne, 368 Lake avenue, Manchester, N. H.

The granite (specimen D, XXX, 82, a) is a biotite granite of medium buff-gray color and of even-grained medium texture, with feldspars up to 0.3 inch, rarely 0.4 inch, and micas under 0.2 inch. The mica scales lie parallel to the rift. Its constituents, in descending order of abundance, are: Greenish-gray potash feldspar (microcline), slightly kaolinized; medium smoky quartz with cavities in sheets; buff-gray soda-lime feldspar (oligoclase-andesine), some of it much kaolinized and micacized; biotite (black mica), some of it chloritized; and a little muscovite or bleached biotite. Accessory: Pyrite, magnetite, allanite, apatite, zircon. Secondary: Kaolin, a white mica, chlorite, calcite. There is no effervescence with the muriatic acid test.

The quarry, opened about 1879, measures about 300 feet from east to west by 150 feet across and 60 feet in depth.

The sheets, 6 inches to 9 feet thick, dip low north on the north side and low south on the south side. There is but one set of joints. This strikes N. 17° W., vertical, is spaced 14 to 22 feet, and forms a 20-foot wide heading on the south side. The rift is reported as horizontal and the grain as vertical with east-west course, both being well marked. The north wall of the quarry is gneiss with thick dikes and lenses of pegmatite. The gneiss foliation strikes N. 80° E. and dips 75° N. 20° W. The south wall is of similar gneiss. The granite thus appears to be a dike 150 feet wide with a north-south strike, crossing a gneiss with a nearly east-west foliation. Rusty stain is up to 8 inches thick on sheet surfaces.

The plant comprises one hand derrick.

Transportation is by cartage to the city.

The product is used for foundations, trimmings, and curbing, for which its marked rift and grain well adapt it.

BODWELL QUARRY.

The Bodwell quarry is about 2½ miles east-northeast of the city hall in Manchester. Operator, T. Paradis, 210 Manchester street, Manchester, N. H.

The granite (specimen D, XXX, 83, a) is a biotite granite of light inclining to medium gray shade and of even-grained medium texture with feldspars to 0.3 inch (exceptionally 0.5 or 0.7). Its constituents, in descending order of abundance, are: Clear, colorless to translucent potash feldspar (microcline), intergrown with quartz, circular in cross section, slightly kaolinized and micacized; light smoky quartz with cavities in sheets; milk-white soda-lime feldspar (oligoclase-andesine), some of it much kaolinized and micacized; biotite (black mica), some of it chloritized. Accessory: Magnetite, allanite. Secondary: Kaolin, white micas, calcite, chlorite. Much effervescence with the muriatic acid test.

The quarry, opened about 1879, measures about 350 feet in a N. 70° E. direction by 65 feet across and 20 to 40 feet in depth.

The sheets, 2 to 6 feet thick, dip 5° S. There is one set of joints only, striking N. 35° W., vertical, spaced irregularly. The rift is reported as horizontal and the grain as vertical with N. 57° E. course. The quarry is walled on its longer sides by banded quartz-mica diorite gneiss of varying texture and pegmatite lenses. The gneiss foliation strikes N. 45° E. There are tongues and inclusions of this gneiss in the granite. Rusty stain is 2 to 3 inches thick on sheet surfaces.

The plant consists of a derrick and hoisting engine, three hand derricks, a steam rock drill, and a steam pump.

Transportation is by cartage.

The product is used for foundations and curbing.

STEVENS QUARRY.

The Stevens quarry is near West Hollis street, in Nashua, 2¼ miles west-southwest of the confluence of Nashua and Merrimac rivers. (See map of Manchester quadrangle, U. S. Geol. Survey.) Operator, Nashua Granite Company, 254 Main street, Nashua, N. H.

The granite (specimen D, XXX, 86, a) is a muscovite-biotite granite gneiss of light-gray shade and of gneissic medium texture, with feldspars under 0.4 inch (rarely 0.7 inch) and micas under 0.2 inch. The rift is at right angles to the foliation. Its constituents, in descending order of abundance, are: Milky potash feldspar (microcline, some of it kaolinized, and orthoclase); light smoky quartz, with hairlike crystals of rutile and granulated (particles 0.05 to 0.25 millimeter across); milk-white soda-lime feldspar (albite to oligoclase-albite), much kaolinized and somewhat micacized; muscovite (white mica) in plates and stringers, which with the granulated quartz surround the larger feldspars; biotite (black mica), a little of it chloritized. Accessory: Garnet, apatite, rutile. Secondary: Kaolin, white micas, chlorite. There is no effervescence with the muriatic acid test.

The quarry, opened about 1840, measures about 175 feet in a northeast direction by 125 feet across and from 10 to 20 feet in depth. The stripping is up to 5 feet thick.

The sheets, from 6 inches to 6 feet thick, dip 10° SE. There are two sets of joints. Set (*a*), striking northeast, vertical, spaced 5 to 20 feet, forms a heading on the northwest wall, one 15 feet from the southeast wall, and a discontinuous one on the northeast wall. Set (*b*), striking N. 60° W., vertical, is less abundant and at irregular intervals. The foliation strikes N. 67° E., dips 90°, and has micaceous faces. The rift is horizontal and the grain parallel to the foliation and the hardway is vertical with northwest strike. A pegmatite dike up to a foot thick, on the northeast side, strikes northeast. A pegmatite lens, 30 by 3 to 4 feet, has the same strike.

The plant consists of two derricks and two hoisting engines, three hand derricks, and a steam pump.

Transportation is by siding from the Boston and Maine Railroad.

The product is used for trimmings and curbing, for which its foliation and marked rift well adapt it, and also for foundations.

MERRIMAC COUNTY.

BAILEY QUARRY.

The Bailey quarry is in Allenstown, 2 miles about north-northeast of Suncook station. Operator, Charles A. Bailey, Suncook, N. H.

The granite (specimens D, XXX, 81, a, b), "Allenstown," is a muscovite-biotite granite of light-gray shade and of even-grained medium texture, with feldspars to 0.3 inch and mica to 0.2 inch, rarely 0.3 inch. In places, owing to flow structure, it is more micaceous than in others. Its constituents, in descending order of abundance, are: Clear, colorless potash feldspar (microcline and orthoclase (?); very light smoky quartz with hairlike crystals of rutile and cavities in sheets; milk-white soda-lime feldspar (oligoclase-albite), kaolinized and micacized; muscovite (white mica); biotite (black mica). Accessory: Apatite, rutile. Secondary: Kaolin, a white mica, calcite. It effervesces slightly with the muriatic acid test.

The quarry, opened about 1874, is on the northwest side of a low granite dome and measures about 500 feet in a northeast direction by 250 feet across and from 20 to 60 feet in depth; the stripping consists of sand averaging 1 foot thick, but the rock is mostly bare.

The sheets, 6 inches to 6 feet thick, dip gently northeast and northwest. There are two sets of joints: Set (*a*), striking N. 60° E., vertical, is rare; set (*b*), striking N. 60° W., vertical, forms a heading 40 feet wide within 200 feet of the northeast end of the quarry. The rift is reported as horizontal and the grain as vertical, with

N. 60° E. course. A hornblende diabase dike 3 to 4 feet wide crosses the quarry lengthwise within 75 feet of the working face, with a N. 60° E. strike and vertical or steep dip. The granite is darker for 14 feet on one side of the dike and 2 feet on the other. (See p. 348.) Three pegmatite dikes, from 14 inches to 5 feet thick, strike about N. 60° W. and dip 45° N. 30° E. to 90°. Some of the granite near the heading of set (*b*) is porphyritic and has large micas. A flow structure appears also in places. Biotitic knots measure to 5 inches.

The plant comprises six derricks at the quarry and two at the cutting shed one-half mile toward Suncook station, three hoisting engines, a small locomotive, an air compressor at the quarry (capacity 338 cubic feet of air per minute), one at the cutting shed on Elm street, Manchester (capacity about 100 cubic feet of air per minute), three large air rock drills, nine air-plug drills, six air hand tools at the sheds, and a stone crusher with meshes of one-fourth, one-half, 1½, and 2½ inches and a capacity of 125 tons per day.

Transportation is by private siding a mile long to the Suncook Valley branch of the Boston and Maine Railroad.

The product is used partly for trimmings but mainly for foundations, curbing, paving, and crushed stone for concrete. Its market is mostly within the State. Specimens: Weston observatory, foundation and trimmings of Coolidge mill and New Manchester mill of the Amoskeag Manufacturing Company, Manchester, N. H.

SHIRLEY QUARRY.

The Shirley quarry is near Merrimac River in Hooksett, 6 miles north of Amoskeag, Manchester. Operator, George N. Shirley, 255 Front street, Manchester, N. H.

The granite (specimen D, XXX, 80, a) is a muscovite-biotite granite of very light gray shade and medium texture, with feldspars and micas to 0.3 inch, the white mica being in rhombic crystals. Its constituents, in descending order of abundance, are: Milky potash feldspar (microcline), slightly kaolinized; clear, colorless quartz with cavities; milk-white soda-lime feldspar (oligoclase-albite), much kaolinized and somewhat micacized; muscovite (white mica), mostly in rhombic crystals; biotite (black mica). Accessory: Magnetite, apatite. Secondary: Kaolin, a white mica, calcite. The stone effervesces with the muriatic-acid test.

The quarry, opened in 1891, is small and was not visited by the writer.

The plant comprises a steam derrick and hoisting engine, two horse derricks at the stone yard at Amoskeag, a small air compressor, a large steam drill, two air-plug drills, and a 14-horsepower steam tug.

The stone is brought down Merrimac River 6 miles in a steam tug to the cutting yard at Amoskeag and carted to its destination.

The product is used for curbing, steps, underpinning, and trimmings. Specimens: Trimmings on Amoskeag school and on Manchester Street Railway car barn.

STRAFFORD COUNTY.

LANGMAID QUARRY.

The Langmaid quarry is in Rochester Township, 5 miles northwest of Dover. Operator, Linville F. Langmaid, 26 South Pine street, Dover, N. H.

The granite (specimen D, XXX, 84, a) is a biotite granite of very light gray shade, with close dark specks, and of even-grained medium texture, with feldspars to 0.3 inch and micas to 0.2 inch. Its constituents, in descending order of abundance, are: Clear to translucent potash feldspar (microcline and orthoclase); medium smoky quartz with cavities in sheets and hairlike crystals of rutile; milk-white soda-lime feldspar (oligoclase-albite), most of it kaolinized and micacized; biotite (black mica), some of it chloritized; and a little muscovite or bleached biotite. Accessory: Magnetite, rutile. Secondary: Kaolin, a white mica, chlorite, calcite. It effervesces slightly with the muriatic acid test.

This is a constructional granite with marked contrast of shade between its smoky quartz and milk-white feldspar.

The quarry, opened before 1879, measures about 300 by 90 feet and from 12 to 15 feet deep. The stripping consists of 2 to 10 feet of loam.

The sheets, 1 to 8 feet thick, are horizontal. There are three sets of joints—a longitudinal, a transverse, and a diagonal set—spaced generally 10 to 20 feet. The rift is reported as horizontal and the grain as vertical with north-south course. There are several pegmatite dikes a few inches thick and one at the edge more than a foot thick. Rusty stain is usually 1 to 3 inches but in places 8 inches thick on sheet surfaces.

The plant comprises one horse and one hand derrick.

Transportation is by cartage 5 miles to Dover or Rochester.

The product is used for bases, trimmings, and faces. Specimen: Some of the trimmings of the court-house at Dover, N. H.

The quarry has been idle for over a year. The thickness of the sheets and the prospective improvement in the quality of the stone are favorable, but its distance from rail is against it.

SULLIVAN COUNTY.

SPECTACLE POND QUARRY.

The Spectacle Pond quarry is at the southeast corner of Sunapee Township, about one-fourth mile south of Spectacle Pond and one-fourth mile southwest of Edgemont (formerly Mount Sunapee) station. (See map of Sunapee quadrangle, U. S. Geol. Survey.) Operator, Ola Anderson, Concord, N. H.

The granite (specimen D, XXX, 78, a), "Spectacle Pond," is a biotite-muscovite granite of light buff-gray shade and of even-grained fine texture, with feldspars to 0.2 inch, rarely 0.25 inch, and micas under 0.1 inch. Its constituents, in descending order of abundance, are: Clear, colorless potash feldspar (microcline and orthoclase); light smoky quartz with hairlike crystals of rutile and with cavities in sheets and cracks parallel thereto; cream-colored soda-lime feldspar (oligoclase-albite), more or less kaolinized and micacized; biotite (black mica); muscovite (white mica). Accessory: Garnet, apatite, rutile. Secondary: Kaolin, a white mica. There is no effervescence with the muriatic acid test.

This is a fine-grained monumental granite. Its shade may be less buff and even bluish farther below the surface.

The quarry, opened in 1909, is 75 feet square and 3 to 8 feet deep. There is little or no stripping.

The sheets, 1 to 5 feet thick, dip 15° about northeast. There are three sets of joints. Set (*a*), striking N. 10° E., dipping 80° W., forms a heading on the east side and is spaced 5 to 10 feet; set (*b*), striking northeast, dipping 65° NW., forms a heading at the southwest corner and is spaced 10 to 25 feet; set (*c*), striking N. 30° E., dipping 70° N. 60° W., forms a heading 10 feet wide through the middle of the quarry. The rift is reported as horizontal and the grain as vertical with nearly east-west course. A quartz vein up to 5 inches thick crosses the middle of the quarry, with N. 70° E. strike and dip of 60° N. 20° W. Rusty stain is up to 4 inches thick on sheet surfaces.

The plant comprises one derrick and hoisting engine, a horse derrick at the station, an air compressor (capacity 175 cubic feet of air per minute), a steam rock drill, and two air-plug drills.

Transportation is by cartage one-fourth mile to rail.

The product of the upper sheets is now being sold for curbing, but that of the lower sheets, when reached, will be used for monuments.

PERRY SUNAPEE QUARRY.

The Perry Sunapee quarry is on the top of a 200-foot knoll one-half mile west of Burkehaven, on Lake Sunapee, and three-fourths of a mile south-southeast of Sunapee village, in Sunapee Township. (See map of Sunapee quadrangle, U. S. Geol. Survey.) Operators, W. H. Perry & Co., Concord, N. H.

Specimens from this quarry (D, XXVIII, 47, a, b), "light Sunapee," were described in Bulletin 354, page 187, but the quarry had not then been visited by the writer. An examination of specimens (D, XXX, 79, a, aa) collected by the writer does not yield any important difference. It is a fine-grained, light, slightly bluish gray monumental granite with biotite and muscovite in about equal amounts, and the second feldspar is oligoclase.

The quarry, opened in 1869, measures about 150 by 100 feet and from 15 to 30 feet in depth.

The sheets, 6 inches to 3 feet thick, are undulating. There are no joints. The rift is probably horizontal and the grain vertical with N. 80° W. course. A pegmatite dike up to 30 inches thick, striking N. 30° E. and vertical or steep, forms part of the east wall. A 3-foot dike striking about east forms the north wall. Other pegmatite dikes up to 6 inches thick, striking N. 50°-70° E., recur at intervals of 5 to 20 feet. A vertical porphyritic granite mass, also striking N. 30° E., forms the west wall. Two large inclusions of quartz-mica diorite gneiss (described more fully on p. 347) occur near the south end of the east wall, apparently in a coarser granite. Biotitic segregations measure to 4 inches across.

The plant comprises a hand and a steam derrick, a hoisting engine, an air compressor, two steam rock drills, and several air-plug drills.

Transportation is by cartage more than 3 miles to Sunapee station, on the Claremont branch of the Boston and Maine Railroad.

The product is used for monuments, which are finished at the firm's cutting shed at Concord. The quarry is operated only occasionally.

CLASSIFICATION OF NEW HAMPSHIRE GRANITES.

In the following table all the granites described are commercially classified, as *constructional*, *monumental*, *inscriptional*, *polish*, *curbing*, and *trimming* granites. Those previously described from this State in Bulletin 354 have been added in their places, so that the table affords a survey of all the granites of the State of known commercial value. The scientific names of the granites are also given and references to the detailed descriptions.

Classification of New Hampshire granites.

CONSTRUCTIONAL.

Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.	Reference.
Concord (various quarries)	Concord	Medium bluish gray	Fine medium, somewhat porphyritic.	Muscovite-biotite granite	Bull. 354, pp. 146-156.
Troy (Troy quarry)	Troy white	Light inclining to medium bluish gray.	Fine	do	Bull. 430, pp. 353-355.
Fitzwilliam (Webb quarry)	Fitzwilliam Webb	Light, very bluish gray	do	do	Bull. 430, pp. 348-349.
Fitzwilliam (Holman quarry)	Fitzwilliam	Light bluish gray	Medium inclining to fine	do	Bull. 430, p. 352.
Fitzwilliam (Silver White quarry).	Silver White	do	Very fine (average diameter, 0.00668 inch).	Biotite-muscovite granite	Bull. 430, pp. 349-350.
Fitzwilliam (Snow Flake quarry)	Snow Flake	Light inclining to medium gray	Porphyritic with fine matrix.	do	Bull. 430, p. 351.
Marlboro (Marlboro quarry)	Marlboro	Light inclining to medium, very bluish gray.	Fine	do	Bull. 430, pp. 352-353.
Stark (Dawson quarry)	Stark	Medium pinkish gray	Medium	Biotite granite	Bull. 430, pp. 356-357.
Canaan (Mascoma quarry)	Mascoma	Light buff-gray	Gneissoid, coarse	Biotite granite gneiss	Bull. 430, pp. 357-358.
Lebanon (Lebanon quarry)	Lebanon pink	Light, faintly pinkish-greenish gray.	do	Epidotic biotite granite gneiss	Bull. 430, pp. 359-361.
Redstone (Redstone quarry)	Redstone red	Light pink mottled with dark gray.	Coarse	Biotite granite	Bull. 354, p. 179.
Madison (Fletcher & Lahey quarry)	Madison	Light pinkish gray mottled with dark purplish gray.	do	do	Bull. 354, p. 185.
North Conway (White Mountain quarry).	North Conway	Medium pinkish buff-gray	do	do	Bull. 354, p. 184.
Kilkenny (Kilkenny quar y)	Kilkenny	Dark olive-green	Medium	Augite-biotite granite	Bull. 430, pp. 355-356.
Milford (Carlton quarry)	Milford building	Medium pinkish gray	Porphyritic	Quartz monzonite, probably.	Bull. 354, p. 175.
Milford (Lovejoy quarry)	do	Light gray	Fine inclining to medium	Quartz monzonite	Bull. 354, p. 160.
Milford (Kittredge and Pease quarries).	do	Light gray with very slight bluish tinge.	do	do	Bull. 354, pp. 161, 163.
Milford (Pease quarry)	Milford building, pink.	Light buff-gray, some slightly pinkish.	do	do	Bull. 354, p. 163.

MONUMENTAL.

Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.	Reference.
Fitzwilliam (Silver White quarry).	Silver White	Light bluish gray	Very fine(average diameter, 0.0068 inch).	Biotite-muscovite granite	Bull. 430, pp. 349-350.
Troy (Troy quarry)	Troy white	Light inclining to medium bluish gray.	Fine	Muscovite-biotite granite	Bull. 430, pp. 353-355.
Haverhill (Pond Ledge quarry)	Pond Ledge gray	Light inclining to medium gray	Fine, but with sparse porphyritic feldspars.	Biotite-muscovite granite	Bull. 430, pp. 358-359.
Do	Pond Ledge pink	Light pinkish gray	do	do	Bull. 430, pp. 358-359.
Sunapee (Spectacle Pond quarry)	Spectacle Pond	Light buff-gray	Fine	do	Bull. 430, pp. 367-368.

Sunapee (Perry quarry)	*Light Sunapee*	*Light slightly bluish gray*	do	With biotite and muscovite in about equal amounts.	Bull. 430, pp. 368–369.
Brookline (O'Rourke quarry)	Brookline	Medium buff-gray	do	Quartz monzonite	Bull. 430, p. 361.
South Brookline (Fessenden quarry).	do	Medium, faintly pinkish gray	Fine (average diameter, 0.0097 inch).	do	Bull. 430, pp. 362–363.
Milford (Young quarry)	Dark blue New Westerly.	Dark gray (smoke color)	Fine (average diameter, 0.0084 inch).	do	Bull. 354, p. 170.
Milford (New Westerly quarry)	New Westerly blue	Medium, slightly bluish gray	Fine (average diameter, 0.009 inch).	do	Bull. 354, p. 173.
Milford (Tonella old quarry)	Milford	Light gray	Fine (average diameter, 0.011 inch).	do	Bull. 354, p. 164.
Milford (Comolli and Paradis quarries).	do	Light inclining to medium bluish gray.	Very fine	do	Bull. 354, pp. 167, 168.
Milford (Souhegan quarry)	do	Dark gray with very slight pinkish tinge.	Fine	do	Bull. 354, p. 168.
Milford (Bishop quarry)	do	Light gray, faintly cream colored.	do	do	Bull. 354, p. 176.
Auburn (Perry quarry)	Deep pink Auburn	Medium pink-buff	do	do	Bull. 354, p. 186.
		INSCRIPTIONAL.			
Sunapee	Black pearl	Very dark bluish gray	Fine to medium	Quartz diorite	Bull. 354, p. 187.
Milford (Young quarry)	Dark blue New Westerly.	Dark gray (smoke color)	Fine (average diameter, 0.0084 inch).	Quartz monzonite	Bull. 354, p. 170.
Milford (Souhegan quarry)	Milford	Dark gray with very slight pinkish tinge.	Fine	do	Bull. 354, p. 168.
		POLISH.			
Madison (Fletcher & Lahey quarry).	Madison	Light pinkish gray mottled with dark purplish gray.	Coarse	Biotite granite	Bull. 354, p. 185.
Redstone (Redstone quarry)	Redstone red	Light pink mottled with dark gray.	do	do	Bull. 354, p. 179.
Do	Redstone green	Dark yellow greenish gray	do	Biotite-hornblende granite	Bull. 354, p. 182.
		CURBING AND TRIMMING.			
Rochester (Langmaid quarry)	Rochester	Very light gray	Medium	Biotite granite	Bull. 430, p. 367.
Manchester (Kennard Ledge quarry).	Kennard ledge	Medium buff-gray	do	do	Bull. 430, p. 363.
Manchester (Bodwell quarry)	Bodwell quarry	Light inclining to medium gray	do	do	Bull. 430, pp 363–364.
Nashua (Stevens quarry)	Nashua	Light gray	Gneissic; medium	Muscovite-biotite granite gneiss.	Bull. 430, pp. 364–365.
Allenstown (Bailey quarry)	Allenstown	do	Medium	Muscovite-biotite granite	Bull. 430, pp. 365–366.
Hooksett (Shirley quarry)	Hooksett	do	do	do	Bull. 430, pp. 366–367.

CONCLUSION.

It will be noticed that the commercial granites of New Hampshire cover a wide petrographic range, including not only a variety of ordinary granites but also quartz monzonite, biotite-hornblende granite, augite-biotite granite, quartz diorite, and gneisses of various sorts.

Economically they consist mainly of the constructional granites of Concord, Fitzwilliam, Marlboro, Lebanon, Canaan, and Redstone and the monumental granites of Fitzwilliam, Troy, Milford, and Brookline.

While the most notable structure of New Hampshire granite is and probably will for many years continue to be the Library of Congress, there are many widely scattered unpretentious but elegant and beautiful monuments of New Hampshire granite, of which the fragmentary lists appended to the quarry descriptions afford evidence.

OOLITIC LIMESTONE AT BOWLING GREEN AND OTHER PLACES IN KENTUCKY.

By JAMES H. GARDNER.

OCCURRENCE AND DISTRIBUTION.

In recent years there has been a steadily increasing demand for oolitic limestone as a building material, which has brought about a notable development of this kind of stone where it is suitably located relative to transportation facilities. The market has been extended over practically the whole of the eastern United States, the supply coming chiefly from the Mississippi Valley. The region producing the greater amount of oolitic limestone is that of Lawrence County and adjacent localities in Indiana, where the familiar Bedford oolitic limestone is extensively quarried. Closely following this Indiana stone in order of importance is the equally celebrated stone from Warren County, Ky., generally known on the market as "Bowling Green oolite."

The stone from the two regions mentioned is similar in appearance and general character and occurs at about the same horizon in the Mississippian series. The "Bedford" limestone of the Indiana Geological Survey, in which the oolitic stone is the most prominent part, is the same as the Spergen limestone of the Meramec group, in which occur most of the Kentucky oolitic limestones, though some beds of western Kentucky are higher in the stratigraphic series and are known to belong to the Fredonia limestone member of the Ste. Genevieve limestone.[a]

Oolitic limestone is exposed at various places throughout a wide area extending from southern Indiana and Illinois across Kentucky into Tennessee and westward into Missouri. It is probable that the most widely extended beds of oolitic limestone are those of the Spergen limestone, which is included in the St. Louis limestone of many authors. Strictly speaking, the St. Louis limestone, as originally described by G. Engelman in 1847 [b] and later limited by B. F. Shumard, [c] includes those limestones above the main oolitic beds. The

[a] Ulrich, E. O., and Smith, W. S. Tangier, Prof. Paper U. S. Geol. Survey No. 36, 1905, p. 40.
[b] Am. Jour. Sci., 2d ser., vol. 3, pp. 119-120.
[c] Geol. Survey Missouri, First and Second Ann. Repts., pt. 2, 1855, pp. 139, 170, and 181.

name Spergen limestone was proposed by Ulrich and Smith[a] for the limestone beds that had previously been called "Bedford" limestone and that lay below the St. Louis limestone (from which they are distinguished by their more or less oolitic character), because the name "Bedford" in a geologic sense conflicted with the better-established term Bedford shale, of the Carboniferous of Ohio.

In Kentucky east of the Cincinnati arch there is a wide area showing exposures of a formation named by M. R. Campbell the Newman limestone.[b] This limestone occupies a position in the stratigraphic column similar to that of the limestones on the opposite side of the arch which were known formerly as the "St. Louis group," that name, however, having been replaced by Meramec group, including both the St. Louis and the Spergen limestone. The Newman limestone has not been subdivided, but the oolitic limestone of Rockcastle and Pulaski counties, which occurs in this formation, will very probably prove to be closely related to the Spergen in age.

The light-gray permanent color of oolitic limestone, its massive and uniform character, and the ease with which it may be dressed, together with its resistance to weathering and pressure, place it first among all American limestones as a building material and second to none for carved and ornamental designs. The beds of the Spergen, the Ste. Genevieve, and the Newman are apparently very persistent and offer fields for commercial development in numerous localities in Kentucky.

BOWLING GREEN STONE.

The oolitic limestone in the vicinity of Bowling Green is in the form of a massive, homogeneous stratum 22 feet thick, overlain by a varying thickness of hard bluish limestone. This oolitic member has an extensive line of outcrop and has been traced westward to the vicinity of Russellville and Elkton and northward across Barren River. The bed is apparently very uniform both in thickness and in character over this area.

The massiveness of the Bowling Green bed is one of the factors that determine its value. Blocks of large dimension can be cut from the quarry face either horizontally or vertically, with no appreciable difference in the appearance or strength of the stone. The quarried blocks average about 4 by 5 by 8 feet, with the greater dimension horizontal. Vertical jointing is slightly developed, but the interval between joint planes is greater than the thickness of the bed. In the construction of buildings the stone may be placed in any position as regards its bedding, with practically no difference in results. The individuality of grains composing the stone and their similarity in composition and size, together with the great uniformity of conditions

[a] Ulrich, E. O., and Smith, W. S. Tangier, Prof. Paper U. S. Geol. Survey No. 36, 1905, p. 30.
[b] Bull. U. S. Geol. Survey No. 111, 1893, pp. 28 and 38.

under which the material was deposited, have resulted in a massive stratum without intermediate bedding planes. The stone is a true oolite, the particles being rounded in shape like the roe of fish, about one-fiftieth of an inch in diameter, and firmly cemented by clear calcite. There is usually intermingled with the grains a small and sometimes considerable percentage of finely comminuted particles of fossil Crinoidea and Bryozoa. The stone when it comes fresh from the quarry is buff-gray, but on exposure to the sun and air soon bleaches to a very light gray. This bleaching is due chiefly to evaporation of a small amount of light, volatile petroleum contained in the stone. This oil is very noticeable by scent in the fresh blocks and in the entire working face of the quarry. For a distance of about 25 feet from the outcrop the stone as shown in the quarries is bleached by the effects of long exposure, the petroleum content being entirely removed from this portion of the bed.

The first quarry near Bowling Green was opened by Belknap & Dumesnile, of Louisville, about seventy-five years ago. This was one, if not the first, of the quarries of oolitic limestone in the Southern States. Work is said to have been done here before any development in the Bedford district of Indiana. One of the earliest companies to begin operations in the vicinity of Bowling Green was the Bowling Green White Stone Quarry Company, the name of which is preserved to the present time. Before the construction of the Louisville and Nashville Railroad the stone was hauled and carried by pack mules to points as far south as Nashville. The corner posts and large gate pillars around the state capitol of Tennessee were constructed of this stone. The capitol building is made of local stone, which shows signs of disintegration, whereas the posts and pillars are little affected by more than fifty years of exposure to the weather.

Quarries now in operation on the "Bowling Green oolite" are as follows: The Bowling Green White Stone Quarry Company and the Oman Bowling Green Stone Company, on adjacent property 5 miles west of town; the Bowling Green Quarries Company, 5 miles northwest; and the Caden Quarry Company, 9 miles northwest of town. The total output of these quarries in the year 1908 was as follows: Rough dimension stone, 111,620 cubic feet, valued at $33,486; and dressed stone, 67,308 cubic feet, valued at $42,654. In connection with the work of the Bowling Green White Stone Quarry Company a considerable amount of the ordinary limestone capping the oolite is crushed for concrete, road metal, and railroad ballast by the Newsom Crushed Stone Company. Practically the entire output of dimension stone is shipped over the Louisville and Nashville Railroad, which is the only rail route; a small quantity is sent to market on barges by Barren and Green rivers.

The stone is quarried by means of steam drills and channelers, handled by steam derricks, and cut by rapid steam pitman saws to blocks averaging about 150 cubic feet in volume. The blocks are shipped in this form to retail stone cutters or dressed to various ornamental designs on the ground. Among prominent buildings constructed of this stone are the following: Custom-house, Nashville, Tenn.; Carnegie Library, Nashville, Tenn.; post-office, Columbia, Tenn.; custom-house, Mobile, Ala.; residences of Alfred Burke, Philadelphia, Pa., and A. M. Lothrop, Washington, D. C.

AVAILABLE STONE NEAR SOMERSET, KY.

In the vicinity of Somerset, Ky., there is a bed of homogeneous oolitic limestone about 25 feet thick. This stratum is in the Newman limestone, which outcrops in an extensive area in this section of the State. The writer made a reconnaissance of this bed in the hills east of the Southern Railway, discovering exposures which warrant the statement that the available stone is of sufficient quantity to justify commercial development. There is no marked disturbance of the strata in this region, the rocks being nearly horizontal and showing few vertical joints. It is probable that this field will be found an attractive one when brought to the attention of those financially interested in this phase of the building-stone industry. The only use of the stone has been by C. H. Lewis, of Somerset, who has quarried a small amount of oolite from Day Knob, 2½ miles east of Somerset, for certain ornamental designs and bases. The stone is similar to the Bedford and Bowling Green stones in general appearance. It is light gray, easily carved because of its granular structure, strong, and durable. Monuments of this stone in the local cemetery have undoubtedly been hardened considerably by exposure.

On the east side of Day Knob the oolitic bed is apparently about 29 feet thick, though a partial cover of débris did not permit a complete measurement at the time of the writer's visit. A clear section of 14 feet was exposed at the top of the bed and 5 feet at the bottom, with an intervening thickness of 10 feet concealed. At this point the oolite is capped by about 50 feet of hard bluish-gray limestone, but the low relief of the knob would permit a wide quarry face of much less overburden.

Three miles south of Somerset and just east of the Southern Railway there is a bed of oolite exposed at a suitable location for development. The writer could not be sure that this is the same bed as that exposed in Day Knob, but it probably is. In this locality the stone shows a thickness of 15 feet, covered by hard bluish-gray limestone. The topography is such that a zone approximately 100 feet wide could be worked over about 50 acres with a cover of not more than 20 feet.

This stone is of a grayish-white color and uniform texture, easily quarried and dressed. It should make a very durable building material and present an attractive appearance in walls of residences. The writer is of the opinion that it would, if properly placed on the market, command a ready sale in the cities of the Blue Grass region of central Kentucky.

OTHER EXPOSURES IN THE STATE.

Besides the areas above described, oolitic limestone is known to occur in the following counties of Kentucky: Barren, Simpson, Logan, Meade, Hardin, Grayson, Caldwell, Todd, Christian, Wolfe, Powell, and Rockcastle.

Of these counties, Barren and Caldwell have produced considerable stone from time to time from points near Glasgow Junction and Princeton. There is little doubt that the stone of these localities is approximately at the same horizon as the Bedford and Bowling Green stones. Oolitic limestone occurring near Princeton and Litchfield is described by G. P. Merrill[a] as follows:

> The oolitic character is very pronounced in these stones, and while in some cases the production of a perfect surface is impossible, owing to the breaking away of these minute rounded grains, still in the better qualities the sharp edges and smooth surfaces are as readily acquired as on the celebrated Bedford (Indiana) or other stones of this character. These are superior to the Bedford stone, moreover, in their clear and uniform colors; Professor Proctor informs the writer that the stone is quarried with ease, is easily wrought, stands pressure well, and is considered one of the most reliable stones of the State.

A sample of the Barren County oolitic limestone near Glasgow Junction was collected by Prof. N. S. Shaler and analyzed by the state chemist.

Professor Shaler's note and the accompanying analysis are quoted below:[b]

> A compact, nearly white, fine oolitic limestone, with a ferruginous stain on the exposed surfaces probably derived from the superincumbent soil.

Analysis of oolitic limestone from near Glasgow Junction, Ky.

Specific gravity	2.678
Lime carbonate	98.050
Magnesia carbonate	.363
Alumina, iron, and manganese oxides	.511
Phosphoric acid	.051
Sulphuric acid	.260
Potash	.115
Soda	.327
Silica and insoluble silicates	1.060
	100.737

[a] Stones for building and decoration, New York, 1903, pp. 308-309.

[b] Kentucky Geol. Survey, vol. 1, new series, 1876, p. 152.

The oolitic limestone, as shown by this analysis, is very high in calcium oxide, and is capable of supplying a clean, white lime when properly burned. Its purity and uniformity and the ease with which it is ground give it a desirable character for use in connection with shale and clay for the manufacture of Portland cement. The Kosmos Portland Cement Company, at Kosmosdale, Jefferson County, is using oolitic limestone from its quarries in Meade County. The stone is ground and mixed with Pleistocene clay of the inner valley of Ohio River. The following is an analysis of this stone made by B. Cushman, of Cornell University, and here quoted from the writer's report on Kentucky clays:[a]

Analysis of oolitic limestone from Meade County, Ky.

Calcium carbonate	98.49
Magnesium carbonate	.42
Silica	.37
Alumina	.12
Ferric oxide	.11
	99.51

The above analysis indicates a stone similar in composition to most oolitic limestones of the Mississippi Valley region.

CONCLUSION.

The oolitic limestone extensively quarried near Bowling Green, Ky., is very similar in character to stone of the same age at Bedford, Ind. The wide distribution of the stone offers opportunities for quarrying at many places in Kentucky favorably located for transportation. The stone has very few objectionable features, and its light-gray color will probably always be in fashion. Oolitic limestone has been used extensively as a building material in prominent structures, is approved by the United States Government in many federal buildings, and is surely growing in favor on the American market. It is therefore safe to predict a steadily increasing demand for this stone and the development of the more important Kentucky localities.

[a] Bull. Kentucky Geol. Survey No. 6, 1905, p. 21.

SURVEY PUBLICATIONS ON BUILDING STONE AND ROAD METAL.

The following list comprises the more important recent publications on building stone and road metal by the United States Geological Survey. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The annual volumes on Mineral Resources of the United States contain not only statistics of stone production, but occasional discussions of available stone resources in various parts of the country. Many of the Survey's geologic folios also contain notes on stone resources that may be of local importance.

ALDEN, W. C. The stone industry in the vicinity of Chicago, Ill. In Bulletin 213, pp. 357–360. 1903. 25c.

BAIN, H. F. Notes on Iowa building stones. In Sixteenth Ann. Rept., pt. 4, pp. 500–503. 1895. $1.20.

BURCHARD, E. F. Concrete materials produced in the Chicago district. In Bulletin 340, pp. 383–410. 1908.

——— Stone. In Mineral Resources U. S. for 1908, pt. 2, pp. 533–579. 1909.

——— Slate. In Mineral Resources U. S. for 1908, pt. 2, pp. 521–532. 1909.

DALE, T. N. The slate belt of eastern New York and western Vermont. In Nineteenth Ann. Rept., pt. 3, pp. 153–200. 1899. $2.25.

——— The slate industry of Slatington, Pa., and Martinsburg, W. Va. In Bulletin 213, pp. 361–364. 1903. 25c.

——— Notes on Arkansas roofing slates. In Bulletin 225, pp. 414–416. 1904. 35c.

——— Slate investigations during 1904. In Bulletin 260, pp. 486–488. 1905. 40c.

——— Note on a new variety of Maine slate. In Bulletin 285, pp. 449–450. 1906. 60c.

——— Recent work on New England granites. In Bulletin 315, pp. 356–359. 1907.

——— The granites of Maine. Bulletin 313. 202 pp. 1907.

——— The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island. Bulletin 354. 228 pp. 1908.

——— The granites of Vermont. Bulletin 404. 138 pp. 1909.

DALE, T. N., and others. Slate deposits and slate industry of the United States. Bulletin 275. 154 pp. 1906. 15c.

DARTON, N. H. Marble of White Pine County, Nev., near Gandy, Utah. In Bulletin 340, pp. 377–380. 1908.

——— Structural materials in parts of Oregon and Washington. Bulletin 387. 36 pp. 1909.

DILLER, J. S. Limestone of the Redding district, California. In Bulletin 213, p. 365. 1903. 25c.

ECKEL, E. C. Slate deposits of California and Utah. In Bulletin 225, pp. 417–422. 1904. 35c.

HILLEBRAND, W. F. Chemical notes on the composition of the roofing slates of eastern New York and western Vermont. In Nineteenth Ann. Rept., pt. 3, pp. 301–305. 1899. $2.25.

HOPKINS, T. C. The sandstones of western Indiana. In Seventeenth Ann. Rept., pt. 3, pp. 780–787. 1896.

——— Brownstones of Pennsylvania. In Eighteenth Ann. Rept., pt. 5, pp. 1025–1043. 1897.

HOPKINS, T. C., and SIEBENTHAL, C. E. The Bedford oolitic limestone of Indiana. In Eighteenth Ann. Rept., pt. 5, pp. 1050–1057. 1897.

HUMPHREY, R. L. The fire-resistive properties of various building materials. Bulletin 370. 99 pp. 1909.

KEITH, A. Tennessee marbles. In Bulletin 213, pp. 366–370. 1903. 25c.

LEIGHTON, HENRY, and BASTIN, E. S. Road materials of southern and eastern Maine. Bulletin 33, Office of Public Roads, Department of Agriculture. 1908. (May be obtained from Department of Agriculture.)

PAIGE, SIDNEY. Marble prospects in the Chiricahua Mountains, Arizona. In Bulletin 380, pp. 299–311. 1909.

RIES, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. In Seventeenth Ann. Rept., pt. 3 (continued), pp. 795–811. 1896.

SHALER, N. S. Preliminary report on the geology of the common roads of the United States. In Fifteenth Ann. Rept., pp. 259–306. 1895.

——— The geology of the road-building stones of Massachusetts, with some consideration of similar materials from other parts of the United States. In Sixteenth Ann. Rept., pt. 2, pp. 277–341. 1895. $1.25.

SIEBENTHAL, C. E. The Bedford oolitic limestone [Indiana]. In Nineteenth Ann. Rept., pt. 6, pp. 292–296. 1898.

SMITH, G. O. The granite industry of the Penobscot Bay district, Maine. In Bulletin 260, pp. 489–190. 40c.

CEMENT AND CONCRETE MATERIALS.

CEMENT MATERIALS IN REPUBLICAN VALLEY, NEBRASKA.

By N. H. Darton.

INTRODUCTION.

With the rapid growth of the cement industry in the United States many limestones are being investigated as to their suitability for cement manufacture. In order to obtain information of this kind an examination was recently made of a portion of the Republican Valley in Nebraska and samples of the limestone of the Niobrara formation were collected. It was found that these limestones could be quarried in large amount at various localities, and analyses show that some of them are well adapted to cement manufacture. Shale is plentiful at most places. Fuel is an important item in preparing cement, but unfortunately coal, which is the only fuel available here, is high priced in this region. It is possible that natural gas may be found, though several unsuccessful attempts to obtain it by deep borings have been made in northern Kansas. The low anticline which crosses the valley near Cambridge has not yet been adequately tested and may possibly yield either gas or oil when the lower strata are reached by the drill.

GEOLOGY OF THE REPUBLICAN VALLEY.

Several years ago a geologic reconnaissance of central southern Nebraska was made under the direction of the writer by G. E. Condra, and the results were set forth in considerable detail in his report.[a]

Southern Nebraska is underlain by several thousand feet of sedimentary strata—limestone, shale, and sandstone in a succession of widespread sheets. They lie nearly level, but have local variations

[a] Geology and water resources of the Republican River valley and adjacent areas: Water-Supply Paper U. S. Geol. Survey No. 216, 1907.

in dip which are not perceptible to the eye. The strata revealed in the Republican Valley dip gently westward except in the anticline in Furnas County, where from Oxford nearly to Cambridge the dips are very gentle to the east. The precise angle at which the strata are inclined has not been ascertained, but they descend only a few feet to the mile.

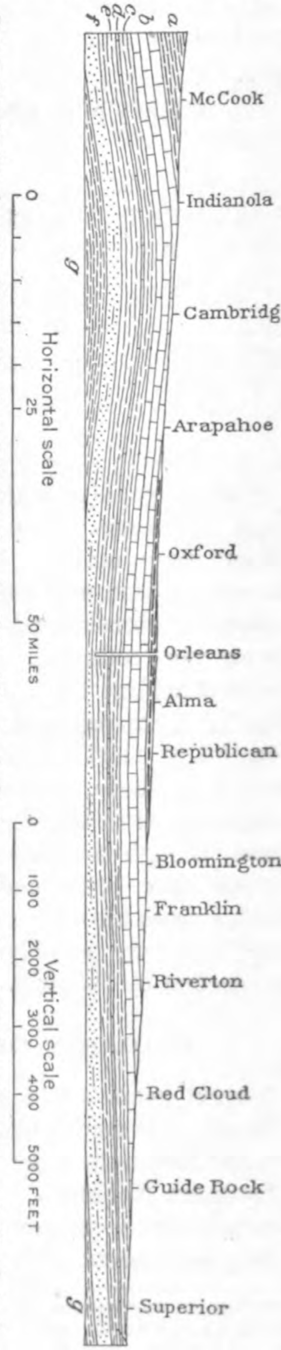

FIGURE 30.—Section along Republican Valley from McCook to Superior, Nebr., following the bluffs. *a*, Pierre shale; *b*, Niobrara formation; *c*, Carlile shale; *d*, Greenhorn limestone; *e*, Graneros shale; *f*, Dakota sandstone; *g*, Permian shale. The Quaternary loess and alluvium and Tertiary grit which cover most of the surface are not shown.

The formations exhibited are of Cretaceous, Tertiary, and Quaternary age, but deeper underground are shales and limestones of the Carboniferous. The Cretaceous rocks are the Dakota sandstone, about 300 feet thick; the Benton group, 300 to 600 feet; the Niobrara formation, 400 feet; and the Pierre shale, 1,000 feet. The Benton group consists of shale with a thin medial member of limestones, and only its upper formation, the Carlile shale, is exposed in the Republican Valley in Nebraska. The Niobrara formation, consisting of chalky limestones and limy shales, underlies all of the central Great Plains and in it is excavated the valley of Republican River. From Indianola to Superior, east of Guide Rock, the valley cuts into the underlying Carlile shale. At Indianola the westerly dip carries the formation beneath the Pierre shale in the bottom of the valley, and from a point near Arapahoe to Naponee the Pierre overlies the Niobrara in a shallow syncline, in places extending nearly to the valley bottom. These relations are shown in figure 30.

The shales and limestones in the Republican Valley region are largely covered by Tertiary grit and Quaternary loess on the adjoining table-lands and slopes and by the alluvium which fills the valley up to the level of the present flood plain. There is also more or less dune sand in part of the region.

LIMESTONE.

DISTRIBUTION.

The limestones of the Niobrara formation are the only ones of any value for cement manufacture in the Republican Valley. They lie at or near the surface through Webster, Franklin, and Harlan coun-

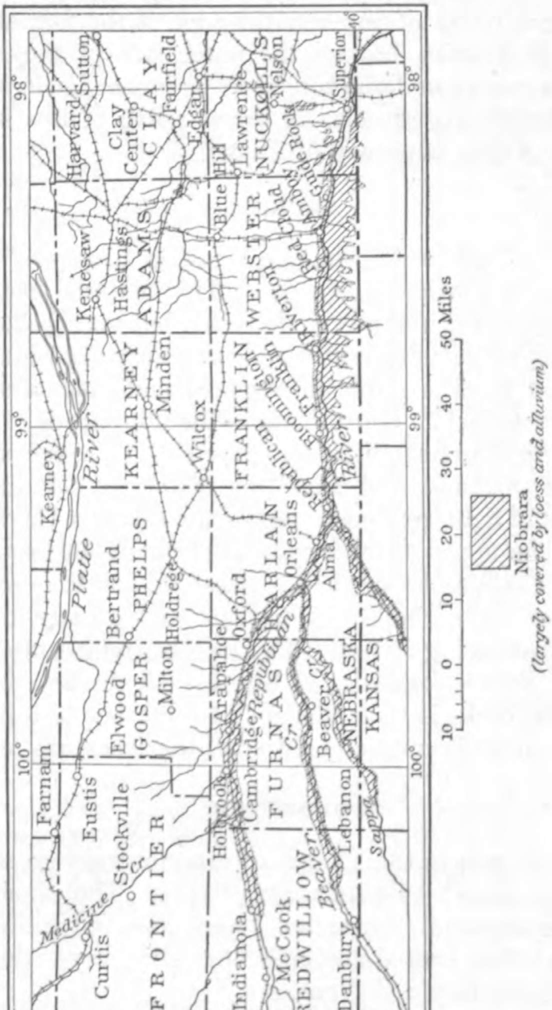

FIGURE 31.—Map showing outcrop area of Niobrara formation in south-central Nebraska. By N. H. Darton.

ties and the eastern half of Furnas County (see fig. 31), but owing to the heavy mantle of loess, talus, and alluvium, outcrops are rare. The most notable exposures are in the river bluffs from Franklin to Superior and in the anticlinal uplift near Cambridge. In the western part of Riverton 30 feet of the massive limestone is exposed and in the bluffs south of Red Cloud and Guide Rock and southwest of Superior there is much limestone. In Harlan County and the eastern part of Furnas County the formation is apparently below the level of the river flats, for the overlying Pierre shale is exposed at places down nearly to the water level. West of Arapahoe the chalky limestone again rises to the surface and on Medicine Creek, 3 miles north of Cambridge, it is so prominent that an extensive quarry has been developed. Southwest of Superior the edge of the formation passes southward into Kansas, but on the north side of the Republican Valley it is known to underlie much of the higher lands of Nuckolls County. Outcrops are revealed in draws north of Bostwick, south of Smyrna, at Nelson, and west of Angus.

ROCKS.

Although the Niobrara formation consists largely of limestone, some of the beds contain much clay. This material occurs mostly as an admixture in the impure "chalk rock," but some beds contain so much that they are calcareous shales. Ordinarily the Niobrara strata are interbedded deposits of soft limestone or chalk and calcareous clay from 5 to 30 feet thick. Flint occurs in the upper beds. Two members of the formation have been recognized. The lower one, averaging 50 feet in thickness and consisting mainly of soft limestone or compact chalk of light-gray color, represents the Fort Hays limestone of Kansas. The upper member consists of about 300 feet of alternations of soft "chalk rock" or chalky limestone and limy shales, all of light-gray color. The chalk-rock deposits vary greatly in thickness, in some places attaining 20 feet. This member represents the Smoky Hill chalk or "*Pteranodon* beds" of Kansas. A characteristic feature of the Niobrara rocks is their tendency to weather to a light-yellow color, though in their unweathered condition they are lead-gray or bluish gray.

COMPOSITION.

The limestone beds in the Niobrara formation vary greatly in composition owing largely to admixture of clay. The upper beds are cherty. Some representative samples were collected and analyzed in the laboratory of the United States Geological Survey with the following results, reported by S. S. Voorhees:

Analyses of limestone from the Niobrara formation in southern Nebraska.

	Riverton.	Two miles southeast of Red Cloud.	South of Guide Rock.	South of Superior.
Lime (CaO)	45.3	37.3	43.3	53.6
Magnesia (MgO)	.8	1.0	.6	.4
Carbon dioxide (CO_2)	35.2	29.3	33.9	42.5
Silica (SiO_2)	6.9	14.7	9.7	1.5
Alumina (Al_2O_3)	3.3	7.1	5.0	1.8
Iron oxide (Fe_2O_3)	1.0	1.7	1.7	.4
Sulphuric anhydride (SO_3)	1.6	.2	.04	.03
Sulphur (S)	.5	.6	.5	.0
Organic matter, etc	4.1	6.3	4.2	.7
	98.7	98.2	98.9	100.9
Lime carbonate ($CaCO_3$)	80.0	66.0	77.0	96.0

These analyses fully illustrate the variations in composition. The rock south of Superior is the massive limestone at the base of the formation, and its purity is notable. The other rocks contain considerable clay, which in the deposits south of Red Cloud is present in such large proportions that purer limestone would have to be added to bring the rock up to the Portland cement standard.

The calcareous grit of the Tertiary deposits covering parts of the high plains has been suggested as a source of Portland cement, but most of the material is too impure. This is shown by the following analysis of a highly calcareous grit from a quarry north of Cambridge not far from the quarry of Niobrara "chalk rock." The analysis was made in the laboratory of the United States Geological Survey and reported by S. S. Voorhees.

Analysis of calcareous grit from quarry north of Cambridge, Nebr.

Lime (CaO)	29.5
Magnesia (MgO)	.6
Carbon dioxide (CO_2)	23.8
Silica (SiO_2)	31.0
Alumina (Al_2O_3)	13.6
Iron oxide (Fe_2O_3)	.4

Much of the silica is in the form of sand grains. The carbonate of lime is too low by 20 per cent.

SHALE.

The Carlile shale, below the Niobrara formation, and the overlying Pierre shale both outcrop extensively in the Republican Valley (see fig. 30), although in many places they are covered by loess on the hillsides and alluvium in the valley. The Pierre shale appears in the banks near Indianola and extends up the valley into Colorado. There are many large exposures in the bluffs along the river, especially in the bends where the river cuts into the highlands on the south side of the valley. This shale also overlies the Niobrara formation in Harlan

County and the eastern part of Furnas County, but is rarely exposed. In some gullies 2 miles south of Orleans it may be seen extending down to the level of the alluvium in the valley bottom. The Pierre shale is nearly uniform in character, consisting of a mixture of clay and fine sand, the latter in somewhat variable proportions. The color is dark, owing largely to admixture with carbonaceous material. The shale is laminated in thin layers but on the surface generally appears as a bank of dark clay.

The Carlile shale, underlying the Niobrara formation, rises above the river level on or near the Webster-Nuckolls county line and appears extensively in slopes and bluffs south of Bostwick and Superior. It is somewhat harder than the Pierre shale and is of lighter-gray or greenish-gray color. The following analysis represents a sample collected in the hills south of Superior, a few feet below the limestone of which the analysis is given on page 385. It was made in the laboratory of the Geological Survey, and the results were reported by S. S. Voorhees.

Analysis of Carlile shale 5 miles southwest of Superior, Nebr.

Silica (SiO_2)	57.8
Oxide of iron (Fe_2O_3)	3.0
Alumina (Al_2O_3)	16.4
Lime (CaO)	.0
Magnesia (MgO)	1.2
Barium sulphate ($BaSO_4$)	1.5
Combined water	3.2
Organic matter	7.1

Considerable shale occurs in the Niobrara formation, most of it containing from 10 to 20 per cent of carbonate of lime.

CONCLUSIONS.

It has been ascertained that the limestone of the Niobrara formation in the Republican Valley is suitable for Portland cement manufacture. Much of it contains more than 75 per cent of carbonate of lime, and it is all very low in carbonate of magnesia, which is a deleterious constituent. It is doubtful if rock containing less than 75 per cent of carbonate of lime could be used except by admixture with purer rock to bring the average up to 75 per cent. Large quantities of the high-grade limestone are available, notably about Riverton and Red Cloud, in the hills southwest of Superior, and on Medicine Creek north of Cambridge. Shale occurs abundantly along the valley, but only in the region southwest of Superior were the limestone and shale found as near together as is desirable to supply a cement plant. There are, however, many localities farther west from which shale could be supplied by a very short shipment, notably the many shale bluffs along the river. No new information was obtained as to fuel. The discovery of oil or gas in the valley would be of greatest advantage, but there is no evidence that either of these fuels could be obtained. A recent boring in Orleans has a depth of 940 feet but failed to reach the Dakota sandstone, which lies but a slight distance deeper. The question as to the presence of oil and gas, especially in the anticline near Cambridge, should be settled by borings sufficiently deep to thoroughly test the shales and limestones that underlie the Dakota sandstone.

MATERIALS REQUISITE FOR CEMENT MANUFACTURE.

The following brief notes on requirements of cement materials probably will be of service to persons interested in the utilization of the deposits in southern Nebraska. The materials required for Portland cement as ordinarily manufactured are carbonate of lime and silicate of alumina—the former generally as limestone or chalk and the latter as shale or clay. Magnesia above 2 or 3 per cent and much sand, flint, or free silica in other forms, are deleterious constituents. The average proportion of carbonate of lime is 75 per cent and of clay 25 per cent. In some places such an admixture is found in the rock itself, but generally the materials are ground separately and mixed in the correct proportions. Ordinarily it would not be considered desirable to use a limestone containing less than 75 per cent of carbonate of lime, but such a rock could be used by admixture with purer limestone, provided the latter could be obtained cheaply. Some shales or clays contain too much fine sand to be used for the manufacture of high-grade Portland cement. The amount of coal used is from 200 to 300 pounds to the barrel (380 pounds) of cement.

The Niobrara chalk rock and overlying Pierre shale are used for cement manufacture at Yankton, S. Dak. This chalk rock contains 83 to 88 per cent of carbonate of lime. The following analyses of the cement materials at this place have been given:[a]

Analyses of Portland cement materials near Yankton, S. Dak.

	Chalk rock.		Shale.	
Lime (CaO)	52.16	51.00	5.28	1.57
Magnesia (MgO)	.14	Trace.	1.72	1.83
Carbon dioxide (CO_2)	41.64	37.99	3.09	....
Silica (SiO_2)	3.83	4.14	61.53	57.98
Iron oxide (Fe_2O_3)	....	2.72	4.01	4.57
Alumina (Al_2O_3)	2.31	1.81	20.74	18.26
Sulphur trioxide (SO_3)	.20	.50	1.26	1.28
Water	....	....	....	12.08

The Niobrara limestone is used extensively for Portland cement manufacture near Florence, Colo. Two kinds of rock are available—one averaging 71 per cent of carbonate of lime and occurring in beds 60 feet thick, and another containing about 88 per cent of carbonate of lime, of which there is a 40-foot bed.

[a] Eckel, E. C., Bull. U. S. Geol. Survey No. 243, 1905, p. 301.

GRAVEL AND SAND IN THE PITTSBURG DISTRICT, PENNSYLVANIA.

By Eugene Wesley Shaw.

INTRODUCTION.

In connection with the detailed geologic survey of several quadrangles in western Pennsylvania in 1908 and 1909, a careful study was made of the alluvial gravel and sand, and the present paper is a brief report on the geology of these extensive and valuable deposits. The area treated includes Beaver, Allegheny, and Armstrong counties. The gravel and sand are found on terraces and in the river bottoms and are of two distinct types, glacial and nonglacial.

The greatest amount of gravel digging has been done in Allegheny County, which has an area of 758 square miles, largely occupied by Pittsburg and its suburbs. In 1909, according to statistics gathered by the United States Geological Survey, this county produced approximately 2,300,000 tons of gravel and sand, the value of which f. o. b. at the point of shipment was over $630,000. These figures exceed those for the output of any other county in the United States; indeed, only seven States have productions as large as this one county.

The sand and gravel resources of several near-by counties are almost as great as those of Allegheny County. Valuable deposits are found along the Allegheny and Ohio, on terraces and in the bottom lands, a large output being taken by dredges from the river beds. The accompanying map (fig. 32) shows the areal distribution of the valuable gravels in the vicinity of Pittsburg.

Western Pennsylvania is a hilly country, and although the river valleys are narrow they offer such uniform and low gradients for railroad building that they are used in preference to more direct routes across the hills. Towns and railroads both are crowded into the valleys, the rivers are navigable, and thus local markets and transportation facilities are in close relation with the gravel deposits. The closeness of this relation, together with the fact that the rocks of the region do not yield very desirable crushed stone, gives to the stream deposits their great commercial importance.

GEOLOGY.

GENERAL OUTLINE.

All gravel and sand is derived from consolidated rocks, and the different kinds owe their characters in part to differences in the parent rocks and in part to the geologic processes which have operated upon them. Well-rounded pebbles represent the most resistant parts of the mass from which they were derived. Soluble rocks, those with decomposable minerals or loosely cemented grains and those having pores or cracks, are broken up sooner or later; rocks of

FIGURE 32.—Map showing principal areas of gravel deposits in the Pittsburg district, Pennsylvania. Hg, High glacial gravels; Lg, low glacial gravels; Hng, high nonglacial gravels; Lng, low nonglacial gravels; R, consolidated rock.

other kinds are preserved and concentrated. Of the resistant class quartz is the most common rock, and for this reason it is found in gravel and sand in much larger proportion than in the country rock. In some places, as, for example, at Canonsburg, quartz pebbles, although only rarely present in the consolidated rocks of the region, were found in a stream deposit where they had been concentrated like gold nuggets in a placer.

The present position of the deposits has also been determined by geologic processes. To illustrate, the sand of the Pittsburg district is of two principal varieties; that of the Allegheny and Ohio valleys is sharp and "hard" and that of the Monongahela Valley is "soft" and round grained. The difference is due to a difference in derivation. Much of the sand of the Allegheny and Ohio valleys comes almost direct from the igneous rocks of Canada, in which the quartz is entirely angular. On the other hand, all the material which the Monongahela carries has been derived from the sedimentary rocks that outcrop in its drainage basin. Most of the sandstones are not resistant and their grains have been reworked several times, so that they are now well rounded. Furthermore, upstream the deposits of the Monongahela decrease in thickness and the materials as a whole are much finer, only the basal portion being as coarse as the glacial gravels of the Allegheny Valley. Most of the rocks that outcrop in the Monongahela basin belong to the Carboniferous system, and the strata consist of micaceous, fine-grained sandstone, generally not very resistant, limestone, shale, and a small amount of conglomerate. The alluvial material derived from these rocks is largely a fine sandy mud, with numerous interbedded lenses of slightly calcareous sand and rounded quartz pebbles.

TERRACE GRAVELS.

Extensive bodies of high-terrace gravels lie on a rock floor 200 feet above the rivers. The glacial and nonglacial gravels are of approximately the same age, but as they have had different origins and are adapted to different uses, they will be treated separately.

EARLY GLACIAL GRAVELS.

The early glacial gravels are found on high rock terraces along the Allegheny and Ohio and have a maximum thickness of over 100 feet. The formation is made up of a heterogeneous mass of well-weathered gravel and sand, varying in kind of rock and in size of pebbles and grains. In many places the basal part is cemented into conglomerate. Some of the pebbles are of granite, diorite, and other igneous rocks, and these must have come from Canada. Others are of the peculiar deep-red Medina sandstone that outcrops in New York but not within the drainage basin of the Allegheny. Some contain silicified fossils, which show them to have been derived from pre-Carboniferous limestones that outcrop in New York but not in western Pennsylvania. Still others are of local origin, having been derived from the layers of hard rock, particularly sandstone, which outcrop abundantly in the region. All these pebbles are mingled with a mass of sand, silt, and clay, the proportionate amount of coarse material being greater than in the nonglacial gravel.

The following section was measured at the gravel pit on Woodlawn avenue, Allegheny, where the elevation of the surface is 232 feet above the river.

Section of high glacial gravels in Allegheny, Pa.

	Feet.
Silt, fine, without pebbles	10
Clay, yellow, and small sand lenses	1–2
Sand and gravel, well-washed pebbles, mostly 0.01 inch to 2 inches in diameter	4–5
Gravel, pebbles, and bowlders up to 4 feet in diameter in a matrix of sand and clay	4–7
Gravel and sand, well washed, with cross-bedding planes sloping downstream	2–3
	24

Above the main body of gravel there are scattered pebbles of local origin, probably remnants of much older stream deposits that have been almost entirely destroyed. Small bodies of local gravel have been found also at some places along the hillward side of the deposit and at many places at the base. These are likewise remnants of preglacial stream deposits. With the exception of the quartz all the pebbles of these very old gravels are so decomposed that they can be crushed in the fingers.

The upper limit of glacial gravel in the vicinity of Pittsburg is about 300 feet above the river. The original upper surface of the formation was at about this position. Up the Allegheny this surface gradually rose, and near Kittanning it was 50 feet higher than at Pittsburg. As a result of erosion the present upper limit of the gravel is not a plane, but the formation thins out irregularly. Probably more than nine-tenths of the original deposit has been carried away by erosion, but many of the most resistant pebbles from it are to be found to-day in lower gravel formations. At present the gravel is found in many isolated deposits, which range up to a mile or more in width and up to 100 feet or more in thickness.

The events which led to this great accumulation of gravel seem to be as follows: An early continental ice sheet, probably the Kansan, covered much of northwestern Pennsylvania to a depth of thousands of feet, stopping all northward drainage and forcing the streams to find outlets to the south. In the readjustment of drainage new parts of valleys were cut, and this process yielded considerable volumes of débris. At the same time the glacier was bringing its load of rock and earth from Canada and New York, and the streams became overloaded. However, the rivers were larger than they are at present, for they were carrying the run-off of all the precipitation that fell on the country south of the area in Canada which formed the center of glacial radiation.

Most of the present valley of the Allegheny and Ohio as far as Beaver was in preglacial time occupied by a smaller river which flowed about 200 feet higher than the present streams. At that time the valley was thus only about half as deep as at present but was nearly a mile wide at the base. With the advent of glaciation alluvial deposits accumulated to a depth of more than 100 feet, although throughout the time during which the overloaded condition lasted the river was carrying away material as rapidly as possible. After the ice disappeared and gradients became somewhat adjusted the overburden decreased, and finally the river was able not only to carry its load but to pick up some that it had dropped. Later it was able to cut down into the hard rock below, to a position 50 feet lower than the present channel. A large part of the old gravel deposit and the older valley bottom beneath has thus been destroyed and the remnants form to-day a high, gravel-capped rock terrace.

NONGLACIAL HIGH-TERRACE DEPOSITS.

High terraces are found also along the Monongahela and other large streams tributary to the Ohio and Allegheny. They are capped with a deposit of sand, clay, and silt, in which are embedded many pebbles and bowlders of sandstone, some of quartz, and a very few of other rocks, but none of glacial material. In general, the coarsest part of the formation is found at the base, and this part is in some places cemented into conglomerate by iron oxide. Above this the central part, comprising more than half the thickness, is made up of sand and silt, with embedded pebbles, many of them flat and arranged in parallel slanting positions. The pebbles are abundant in certain lenticular layers, but in other parts are almost entirely absent. The uppermost layers of the formation are commonly composed of sand and silt. A very few lenses are approximately free from clay. Nearly all parts of the formation contain too much fine material to be valuable as sources of gravel.

Several different views have been held concerning the origin of these high nonglacial deposits and the topographic features connected with them. Some of the earliest workers believed that the terraces were due to submergence and marine erosion. Others have ascribed the deposits to a large ice dam at Cincinnati or Beaver. Still others look upon these features as the result of stream work, but do not go into details of development; and at least one worker believes that certain of the abandoned parts of valleys owe their existence to huge local dams of ice. The writer has presented the view that all the high-terrace deposits were developed as a unit, through the overloading of the Allegheny and Ohio in glacial time, the deposits on those streams choking the tributaries and causing them to partly fill the lower ends of their valleys.

INTERMEDIATE TERRACE GRAVELS.

Below the high terraces and above the present flood plains, particularly on the Allegheny and Ohio, there are at many places terraces of varying age, but younger than the early glacial and older than the recent. Commonly there is no perceptible rock shelf under them, and the deposits are composed of gravel, sand, clay, and silt, not so deeply weathered as the higher deposits. In few places does the thickness exceed 15 feet. Some of the deposits may mark an overloaded stage of the river, or all may be remnants of ordinary flood-plain deposits made in the course of the stream's downward cutting. They are of too small extent to be of commercial value.

LATE GLACIAL GRAVEL.

Along Allegheny and Ohio rivers is a continuous thick deposit of gravel derived from a great variety of rocks occurring in Canada, New York, and Pennsylvania. Much of the material has been reworked by the streams and might properly be called recent alluvium, but the original deposit and the reworked part are so much alike in constitution and lie so nearly at the same position that for present purposes they are better treated together. This gravel is the most valuable in the region and extends from approximately 100 feet above low water to 50 feet below. The present thickness ranges up to about 130 feet, and probably the original thickness was slightly greater. The pebbles and bowlders are well rounded and constitute the most conspicuous part of the formation. In diameter they range up to a foot or more, though most of them are between 1 and 3 inches. The proportion of different kinds of rocks varies. Sandstone is most abundant; quartz and igneous rocks are present in nearly equal amounts; chert pebbles are numerous. Some well records indicate that the coarseness increases with increasing depth; others that the proportion of sand and silt increases down to the basal layers, which are generally coarse. However, all the pebbles are embedded in a matrix of sand and clay, and even where they are coarsest there is considerable interstitial space occupied by the finer materials. The pebbles are much less deeply weathered than those found on the high terraces, and the upper surface of the later deposit has not been so profoundly modified by the streams.

The largest area of late glacial gravel is found in the lower part of the city of Allegheny, and in this connection it is interesting to observe that certain characters and relations of this formation give it an important geographic bearing. Its surface is level but easily excavated, and although above the reach of high water, yet it is near the river, a position which is important with respect to water supply, power, and commerce; it contains immense supplies of sand and gravel; it is usually present along both sides of the river; and though throughout most of its extent it is narrow it locally broadens to a mile or more and thus presents admirable sites for towns, manufacturing plants, and railroads.

The following well section is typical. The elevation of the surface at the well is 70 feet above the river.

Well section at Sewickley, Pa.

	Feet.
Silt, gravelly, yellow	9
Gravel, coarse	4
Sand	8
Sand, gravelly	40
Mud, blue	8
Sand and gravel	25
Sand and bowlders	14
	108

The mode of development of the lower glacial gravel seems to be similar to that of the higher gravel. In interglacial time the rivers had apparently cut to 50 feet or so below their present position. With the advent of one of the late ice sheets, probably the Wisconsin, the Allegheny and Ohio again became overloaded with débris and again built a valley train, thicker than the earlier though not so broad. The volume of the lower deposit was probably somewhat smaller than that of the earlier gravel, but so much less of the later material has since been carried away that at present it is much more important. Though the Ohio is a large and powerful river, it has not yet cut through the deposit to its former position and is still laboring with its glacial burden.

Thus the lower gravel marks a time when the rivers, being overloaded with glacial débris, left some of the coarser, less easily transported material in their beds and along their banks, and in this way partly filled their valleys. The numerous bowlders of sandstone from near-by districts, ranging up to 4 or 5 feet in diameter, suggest that the rivers were somewhat larger than now; indeed, it is likely that they were to a greater or less degree glacial torrents.

The pebbles are the most resistant parts of the many kinds of rocks which are within reach of transportation or which outcrop to the north. They have traveled far, the journeys and the age of the most resistant being the greatest.

LATE NONGLACIAL GRAVEL.

The lower reaches of the Monongahela and other tributary streams flow over beds of gravel which, except for their slight weathering, closely resemble the nonglacial high-terrace deposits. Near Pittsburg the base of this late nonglacial gravel lies about 45 to 50 feet below and the upper limit 100 feet above low water. Upstream the deposit rises and thins, and at the West Virginia line it has the thinness and other characters of an ordinary flood-plain deposit. The Monongahela does not flow on a bed-rock channel anywhere within the State of Pennsylvania. At many places the river has swung into the side of the valley, leaving the deposit on the opposite side, and has laid consolidated rock bare, but nowhere does hard rock extend across the full width of the river.

The late nonglacial gravel contains considerable bodies of clean sand and many of these have been worked. The sand differs from the sand of Allegheny River in being round grained. The pebbles are also well rounded. Many of them are rather flat, but few are angular. On the whole, there is much more fine material in this deposit than in the late glacial gravel.

Where covered with water the upper 2 or 3 feet of gravel and sand harden in a way that suggests cementation. On exposure to the air the sand again becomes loose. Hardening is said to take place in about three years.

The following well section at McKeesport illustrates the character of the deposit. The elevation of the well is 40 feet above the river.

Section of well at McKeesport, Pa.

	Feet.
Silt, sandy	8
Sand, with quartz pebbles and sandstone bowlders	11
Sand, with some silt	20
Mud, blue	11
Sand, with quartz and sandstone pebbles	19
Sand, clean	8
Mud. sandy with many bowlders	12
	89

DEVELOPMENT.

The alluvial gravel and sand of the Pittsburg district are worked and prepared by two principal methods. The larger part of the production is dredged from the river bottom and a smaller part is taken from ordinary pits.

DREDGING.

In dredging, a favorable spot is chosen where the gravel is loose and of desirable quality. The material is brought up by bucket endless chains and is screened and washed with one handling. Gravel is usually loaded on barges on one side of the dredge, while sand is loaded on the other. Several different sizes of gravel are produced. A 3-inch mesh screen is used for general heavy concrete gravel; 1½ inch for material for sidewalks and small reinforced concrete. Frequently ¾-inch gravel also is screened out. The average amount of gravel and sand obtained in the material worked is variously estimated at 15 to 30 per cent. It is often said that the bowlders and fine waste occupy almost as much space as the original deposit. In ordinary stages of the river dredging operations are carried on more extensively on the Allegheny, but in times of low water most of the gravel is taken from pool No. 1 on the Ohio. A small amount is taken every year from the Monongahela, but the sand and gravel of this stream are of so much lower value that the deposits are not worked extensively.

If it were not that the river were constantly bringing in fresh supplies of valuable gravel and uncovering new bodies, the bed of the river would soon be picked over and the available deposits so depleted as to be worthless, but although millions of tons of gravel and sand have been taken from the rivers, the only effect has been to reduce the proportion of available material. Several miles away somewhat "better picking" is now found than in the vicinity of Pittsburg. From points 35 miles or more up the Allegheny gravel is being brought to Pittsburg, and dredging for local markets is carried on at a considerably greater distance.

STRIPPINGS AND PITS.

Several large strippings and numerous small pits are opened on the extensive flood plain and terrace deposits of the area, but the yield from these openings is much smaller than that from the river beds. The principal reason is that the expense of working the land deposits is considerably greater than the cost of dredging, but an additional reason is that the gravels, particularly those on the high terraces, are somewhat decayed and therefore not so valuable as the product of the river bed. Nevertheless the terrace deposits are worth working, and operations on them are increasing in extent as the more valuable and more easily accessible parts of the river gravels are exhausted. At an extensive stripping on Woodlawn avenue, Allegheny, about 15 feet of naturally well-washed sand and gravel are worked. The overburden is here 10 feet or more thick and is removed by scrapers. Most of the pebbles are under 2 inches in diameter, but many are larger and there are a few bowlders 3 to 4 feet in diameter. The sand grains consist almost exclusively of quartz. Among the pebbles sandstone predominates, but quartz is abundant and igneous and metamorphic rocks are common. Small lenses of sand are numerous. There are also cherty pebbles, probably from the Onondaga limestone of New York, deeply decayed "Corniferous" limestone pebbles, and a few pebbles of Silurian rocks.

About half a mile east of the Woodlawn avenue pit is another, showing 3 to 4 feet of nearly white clay at the base, overlain by well-washed gravel, with pebbles mostly 1 to 2 inches in diameter but many smaller. The deposit contains a few subangular sandstone bowlders which have probably not traveled far. Pebbles of igneous rock are common, and there are a few of conglomerate and many of quartz. Fossiliferous pebbles from New York are numerous. The gravel is screened by hand, the meshes of the screens being about 3 inches and one-fourth inch.

In Pittsburg, near the United States arsenal and Liberty street, the James Jiles Company works a gravel for mill and foundry sand. The whole deposit, including sand, gravel, and silt, is ground together. A short distance away Evan Jones & Co. make paving brick of the terrace clay and sand. There are many other pits, but these are typical and give a fair idea of the character of the deposit and the methods of working.

USES.

Immense quantities of gravel have been used in street foundations in this region. Almost the entire length of Pittsburg's 300 miles of streets is founded upon a gravel base having an average thickness of 9 inches. Possibly a still larger amount has been used in concrete. The Government has built 12 locks on the rivers of this district, and the average quantity of gravel and sand used in each was 50,000 cubic yards, or approximately 67,500 short tons. The gravel seems to be quite satisfactory in concrete work, 25 per cent of good cement generally being used. The concrete made in this way will break across the pebbles and not around them.

In many parts of the United States gravel is extensively used as railroad ballast, but in the vicinity of Pittsburg the iron and steel works yield large quantities of slag and the railroads use this material for ballast.

The new filtration works at Pittsburg will use 68,300 cubic yards of filter gravel and 245,900 cubic yards of filter sand. There are fifty-six 1-acre filters and each is to have a basal layer of gravel about a foot thick and an upper layer of sand about 2½ feet thick. The gravel is of four sizes and was bought by contract at two different times for $1 and $1.74 a cubic yard. The sand was also bought by contract, the prices paid being 85 cents and $1.49 a cubic yard. All of the filter material is being obtained from the bed of Allegheny River, opposite the filtration works, about 7 miles above the junction of the Allegheny and the Monongahela. At this place the river-bed deposit conforms so closely with the requirements for filter sand and gravel that very little screening and washing is necessary. The following quotation[a] gives the principal specifications for filter material at these works:

FILTER GRAVEL.

SEC. 20. Four different classes of filter gravel shall be used as hereinafter specified. Filter gravels known as Nos. 1 and 2 may be hard, durable stone, broken and screened to the proper sizes, or gravel screened from river deposits or banks of a sandy nature. Filter gravels known as Nos. 3 and 4 shall be rounded gravel only, screened from deposits of a sandy nature. Filter gravels Nos. 1, 2, and 3 shall be rendered free from sand.

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[a] Contract and specifications for filter material for additional filters, situate in O'Hara Township, Allegheny County, Pa. (contract No. 11-H, city of Pittsburg, Pa.), Department of Public Works, Bureau of Filtration, 1908, pp. 42, 43, 46, 47.

Gravel screened from hardpan or clayey materials can not be sufficiently cleaned. Broken stone or gravel shall not be of or contain more than a small amount of shale or imestone. Broken stone shall be of well-formed, nearly rectangular stones, and shall not contain thin, flat, or long, sharp angular pieces.

SEC. 21. Filter gravel shall not contain more than 2 per cent of lime and magnesia and other matter soluble in water or a weak solution of hydrochloric acid, taken together and calculated as carbonate.

SEC. 22. The filter gravel shall be divided into four classes known as Nos. 1, 2, 3, and 4. Each class shall be uniformly graded and shall meet the requirements given in the following table, screening being performed with rated sieves in the manner now being used by the bureau. Sizes down to and including seven sixty-fourths of an inch will be measured by means of finished plates having circular holes whose diameter is the specified size. For sizes under seven sixty-fourths of an inch, sieves will be used having a clear mesh of the specified size.

Size.	No. 1 gravel.		No. 2 gravel.		No. 3 gravel.		No. 4 gravel.	
	In.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
100 per cent shall pass	3	76.2	$1\frac{1}{2}$	38.1	$\frac{1}{2}$	12.7	$\frac{3}{16}$	4.8
100 per cent shall be retained on	$1\frac{1}{2}$	38.1	$\frac{1}{2}$	12.7	$\frac{3}{16}$	4.8	......	1.8
Not more than 10 per cent shall pass	$1\frac{9}{16}$	39.7	$\frac{19}{32}$	15.1	$\frac{7}{32}$	5.6	......	1.0
At least 10 per cent shall pass	$1\frac{31}{32}$	50.0	$\frac{13}{16}$	20.6	$\frac{9}{32}$	7.1	......	1.8

FILTER SAND.

SEC. 31. Sand before it is distributed in the filters and from that time until final acceptance shall have a cleanliness represented by the following conditions: When 100 grams of filter sand are thoroughly shaken up in a beaker containing 1 liter of distilled water, the resulting turbidity of the water shall not exceed 200 parts per million by the silica standard. Sand showing a cleanliness less than this will be rejected.

SEC. 32. Filter sand shall be clean Allegheny River sand, or its equivalent in all respects, and shall not contain over 1 per cent by weight of flat, laminated, or micaceous particles. It shall be entirely free from clay, dirt, coal, or organic impurities and shall be screened and washed to remove such materials. All grains shall be of hard material which will not disintegrate.

SEC. 33. Filter sand shall contain at least 92 per cent of silica and insoluble residue and shall not contain more than $1\frac{1}{2}$ per cent of lime and magnesia, taken together and calculated as carbonates; all being determined by treating the sand by boiling with 10 per cent of hydrochloric acid. Other conditions being equal, preference will be given to the sand which is lightest in color.

SEC. 34. The filter sand shall be of uniformly graded material from coarse to fine and conform to the following requirements as to size. The diameter of the sand grains shall be computed as the diameters of spheres of equal volumes.

Not more than one-half of 1 per cent by weight shall be less than 0.16 millimeter; not more than 10 per cent by weight, less than 0.28 millimeter; at least 10 per cent by weight shall be less than 0.36 millimeter; not more than 60 per cent by weight shall be less than 0.6 millimeter; at least 60 per cent by weight shall be less than 0.75 millimeter; and at least 90 per cent by weight shall be less than 2.1 millimeters. No particles shall be more than 5 millimeters in diameter, and the sand shall be passed through screens or sieves of such mesh as to stop all such particles, and no screens or sieves shall be used which contain at any point holes or passages allowing grains larger than 5 millimeters to pass.

Some of the Allegheny River sand is usable for grinding plate glass. Uniformity of size seems to be an important requirement of sand for this purpose. At Ford City large quantities are used until ground fine and then washed back into the river. However, much of the river sand is not suitable for this work. Certain sands seem to be desirable in purity, size, and angularity of grain and appear to the untrained eye to be like that which is used successfully, but are nevertheless worthless, because they contain here and there coarse grains known to the operators as "lice." The sand of the Allegheny Valley is also used for many other purposes, including molding, building, and filtration. Furnace, engine, and fire sands and other kinds are produced in less quantity. The sand of Monongahela River is used in grout, for furnace bottoms, in mills, and in street paving.

The high-terrace deposits of the Monongahela are less valuable than those of the Allegheny and have not been worked extensively. They are, however, used locally in many areas; for example, sand and silt from these terraces were used for the diamond of the new baseball park in Pittsburg.

PRODUCTION AND VALUE.

The following table gives the amount and value f. o. b. at the point of shipment of the stream sand and gravel produced in Allegheny, Beaver, and Armstrong counties in 1909:

Production of stream sand and gravel in Allegheny, Beaver, and Armstrong counties, Pa., in 1909.

	Quantity (short tons).	Value.
Sand:		
Molding sand	107,550	$81,225
Building sand	1,047,963	345,713
Sand for grinding plate glass	144,467	78,284
Other sands, including fire, engine, furnace, and filtration sands	10,550	6,010
Gravel	1,254,631	210,831
	2,565,158	722,063

In this region the highest priced stream-laid sand is that sold for filtration purposes, and this brings over $1 a ton. The others, in order of their value, are fire sand, engine sand, furnace sand, molding sand, sand for grinding glass, and building sand, the last named selling for about 30 cents a ton. The average selling price of gravel f. o. b. at the point of shipment is about 15 cents a ton, or half the price of the cheapest sand. Retail dealers deliver gravel in small amounts for about 8 cents a hundred pounds.

The demand for sand and gravel will probably continue to increase, and as the river-bed deposits become thoroughly picked over and the better and more easily accessible parts become exhausted, attention will be turned to the higher deposits, which contain much valuable material, are well drained, have generally little overburden, and may be easily worked by hand or steam shovel.

SURVEY PUBLICATIONS ON CEMENT AND CEMENT AND CONCRETE MATERIALS.

The following list includes the principal publications on cement materials by the United States Geological Survey, or by members of its staff. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Besides the publications cited, the Survey has in preparation bulletins dealing with the results of tests on concrete beams and the constituent materials of concrete, etc.

ADAMS, G. I., and others. Economic geology of the Iola quadrangle, Kansas. Bulletin 238. 80 pp. 1904.

BALL, S. H. Portland cement materials in eastern Wyoming. In Bulletin 315, pp. 232–244. 1907.

BASSLER, R. S. Cement materials of the valley of Virginia. In Bulletin 260, pp. 531–544. 1905. 40c.

BURCHARD, E. F. Portland cement materials near Dubuque, Iowa. In Bulletin 315, pp. 225–231. 1907.

——— Concrete materials produced in the Chicago district. In Bulletin 340, pp. 383–410. 1908.

BUTTS, C. Sand-lime brickmaking near Birmingham, Ala. In Bulletin 315, pp. 256–258. 1907.

——— Ganister in Blair County, Pa. In Bulletin 380, pp. 337–342. 1909.

CATLETT, C. Cement resources of the valley of Virginia. In Bulletin 225, pp. 457–461. 1904. 35c.

CLAPP, F. G. Limestones of southwestern Pennsylvania. Bulletin 249. 52 pp. 1905.

CRIDER, A. F. Cement resources of northeast Mississippi. In Bulletin 260, pp. 510–521. 1905. 40c.

——— Geology and mineral resources of Mississippi. Bulletin 283. 99 pp. 1906.

DARTON, N. H. Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming. Professional Paper 65. 104 pp. 1909.

——— Structural materials in parts of Oregon and Washington. Bulletin 387. 36 pp. 1909.

DARTON, N. H., and SIEBENTHAL, C. E. Geology and mineral resources of the Laramie Basin, Wyoming. Bulletin 364. 81 pp. 1908.

DURYEE, E. Cement investigations in Arizona. In Bulletin 213, pp. 372–380. 1903. 25c.

ECKEL, E. C. The materials and manufacture of Portland cement. In Senate Doc. 19, 58th Cong., 1st sess., pp. 2–11. 1903.

——— Cement-rock deposits of the Lehigh district. In Bulletin 225, pp. 448–450. 1904. 35c.

——— Cement materials and cement industries of the United States. Bulletin 243. 395 pp. 1905. Edition exhausted. Available for reference in libraries of cities and educational institutions.

——— The American cement industry. In Bulletin 260, pp. 496–505. 1905. 40c.

——— Portland cement resources of New York. In Bulletin 260, pp. 522–530. 1905. 40c.

——— Cement resources of the Cumberland Gap district, Tennessee-Virginia. In Bulletin 285, pp. 374–376. 1906. 60c.

——— Cement industry in the United States in 1908. In Mineral Resources U. S. for 1908, pt. 2, pp. 441–453. 1909.

ECKEL, E. C., and CRIDER, A. F. Geology and cement resources of the Tombigbee River district, Mississippi-Alabama. Senate Doc. 165, 58th Cong., 3d sess. 21 pp. 1905.

HUMPHREY, R. L. The effects of the San Francisco earthquake and fire on various structures and structural materials. In Bulletin 324, pp. 14–61. 1907. 50c.

——— Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo. Bulletin 329. 85 pp. 1908.

——— Portland cement mortars and their constituent materials: Results of tests, 1905 to 1907. Bulletin 331. 130 pp. 1908. 25c.

——— The strength of concrete beams; results of tests made at the structural-materials testing laboratories. Bulletin 344. 59 pp. 1908.

——— The fire-resistive properties of various building materials. Bulletin 370. 99 pp. 1909.

LANDES, H. Cement resources of Washington. In Bulletin 285, pp. 377–383. 1906. 60c.

MARTIN, G. C. The Niobrara limestone of northern Colorado as a possible source of Portland cement material. In Bulletin 380, pp. 314–326. 1909.

PEPPERBERG, L. J. Cement material near Havre, Mont. In Bulletin 380, pp. 327–336. 1909.

RICHARDSON, G. B. Portland cement materials near El Paso, Tex. In Bulletin 340, pp. 411–414. 1908.

RUSSELL, I. C. The Portland cement industry in Michigan. In Twenty-second Ann. Rept., pt. 3, pp. 620–686. 1902.

SEWELL, J. S. The effects of the San Francisco earthquake on buildings, engineering structures, and structural materials. In Bulletin 324, pp. 62–130. 1907. 50c.

SMITH, E. A. The Portland cement materials of central and southern Alabama. In Senate Doc. 19, 58th Cong., 1st sess., pp. 12–23. 1903.

——— Cement resources of Alabama. In Bulletin 225, pp. 424–447. 1904. 35c.

TAFF, J. A. Chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements. In Twenty-second Ann. Rept., pt. 3, pp. 687–742. 1902.

CLAY.

FULLER'S EARTH AND BRICK CLAYS NEAR CLINTON, MASSACHUSETTS.

By William C. Alden.

During the final melting of the Pleistocene glacier from central Massachusetts considerable bodies of water were held by the retreating ice front in some of the valleys which formerly discharged toward the north. The largest of these temporary glacial lakes, to which W. O. Crosby has given the name Glacial Lake Nashua, occupied the valley of Nashua River in the vicinity of Clinton, Mass. There were several stages of this lake, due to the opening of successively lower outlets as the ice front retreated northward. These stages were characterized by extensive deposition of sand, gravel, and silt.

The history and deposits of this ancient glacial lake have been discussed by Professor Crosby[a] in connection with studies covering the building of the Wachusett reservoir dams. They are also treated in the forthcoming Quinsigamond folio of the Geologic Atlas of the United States.

The deposits representing the latter part of the Clinton stage of this lake are fine laminated silts, now overlain by sand and gravel of a terrace of a later stage. The best exposure of these clays is at the New England Brick Company's plant, half a mile west of Still River station, where an excavation is being made in the abrupt margin of a broad terrace. The upper 10 to 12 feet consists of cross-bedded sand and fine gravel, forming the terrace top. Beneath this material and above the level of the floor of the valley is exposed 12 to 14 feet of blue, stoneless, laminated clay, with alternate layers slightly sandy and less dense. The depth to which this clay extends below the level of the valley floor is not known, but at one point a low ridge of stony blue clay rises a few feet above the floor, and the laminæ of the clay above dip with the slope of its surface. About the middle of the section are three beds, 1½ feet, 1 foot, and 10 inches in thickness, in which the laminæ are closely crumpled in little folds.

[a] Tech. Quart., vol. 16, 1903, pp. 240-254; vol. 17, 1904, pp. 37-75.

Between, above, and below these beds are regular undisturbed laminæ. The little folds are not regularly overthrust toward the south, there is no coarse or unassorted drift on the several contorted layers, nor is there other evidence of a readvance of the ice front, such as would indicate that the glacier had thrice overridden the laminated silts. It is more probable that the contortions were caused by repeated groundings of icebergs or ice floes on the soft clay bank. The rising, sinking, and turning of such grounded masses with the movement of the water might contort the clay laminæ to a depth of a few inches, as is seen here. Continued deposition after each interruption covered the disturbed beds with regular laminæ. The clay is exposed in the bank for some distance northward. Just south of the pit the surface of the clay drops down in the section, so that for some rods north of the road the whole section is made up of stratified sand and gravel. Similar clay is also exposed at an old brickyard on the east side of the valley about three-fourths of a mile north of Still River station. It is reported that clay was dug for brick some thirty years ago in the lower slope east of Whittemore Hill, at the Burbank place.

One mile northeast of Lancaster, just east of the railway, a pit owned by E. and R. M. Farnsworth exposes 8 feet of laminated clay beneath 5 feet of sand and gravel. Except the upper 1 foot, which contains some pebbles, the clay is almost wholly without stones, though a few berg-dropped bowlders are present in the deposit. It is said that a thickness of at least 26 feet was shown at one point by excavation and boring, and that the deposit thins up the slope to 8 feet at the west side of the railway, the average being perhaps 15 feet. Lower down the slope to the east the stony blue till is exposed. The laminæ of the clay are slightly undulating, and it is said that in places in digging they have been found folded and tipped up on edge. These laminated silts were evidently deposited in the open lake and not in the immediate vicinity of the ice front, being free from coarse detritus except that dropped from floating ice. It is believed that they were laid down in the waters of the Clinton stage of the lake, while the ice front stood at the moraine 2 or 3 miles north of Still River station. The material is used for fuller's earth and is, so far as the writer has ascertained, the only glacial silt so used anywhere. It is also reported that this clay is being used as a binder in the manufacture of emery stones.

Lacustrine clays adapted to brick manufacture in this region appear to be confined to the Nashua Valley north of Clinton, though they may occur in other basins beneath the coarser sand and gravel or marsh deposits. The blue clay taken from the pit of the New England Brick Company half a mile west of Still River station is mixed with some sand and made by machinery into common pressed brick. A kiln of this brick is said to require about ten days to burn with wood. Similar clay was formerly used at Bailey's brickyard, three-fourths of a mile north of Still River station, on the east side of the valley, and at an early day brick was made on the Burbank place, east of Whittemore Hill, from clay excavated near the edge of the marsh.

Examination of these clays under the microscope shows them to be composed of minute angular fragments of various minerals, principally quartz and feldspar, ranging from a very uniform upper limit of grains one-eighth to one-half millimeter in diameter down to the limit of vision. A sample from the New England Brick Company's clay bank shows the grains to be very uniform in character, but a small percentage being larger than one-seventieth of a millimeter in diameter. Clay taken from the middle of two of the exposures showed the following chemical composition:

Analyses of clays from Worcester County, Mass.

[George Steiger, analyst.]

	1.	2.
SiO_2	66.65	57.88
Al_2O_3	16.93	20.68
Fe_2O_3	3.05	3.94
FeO	.84	2.08
MgO	.96	1.60
CaO	1.07	1.03
Na_2O_3	2.05	1.99
K_2O	3.60	4.74
H_2O-	1.54	1.38
H_2O+	3.03	3.63
TiO_2	.80	.88
CO_2	None.	....
	100.52	99.83

1. Farnsworth pit, northeast of Lancaster. 2. Brickworks west of Still River station.

These clays are well adapted to the manufacture of common brick and, being largely free from pebbles, would probably make earthenware of low grade, such as flowerpots. The high percentages of alkalies and other fluxes, however, render them unsuitable for vitrified products.

SURVEY PUBLICATIONS ON CLAYS, FULLER'S EARTH, ETC.

In addition to the papers named below, some of the publications listed under the heading "Cement" contain references to clays. Certain of the geologic folios also contain references to clays, fuller's earth, etc.

These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Those marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

Ashley, G. H. Notes on clays and shales in central Pennsylvania. In Bulletin 285, pp. 442–444. 1906.

Ashley, H. E. The colloid matter of clay and its measurement. Bulletin 388. 65 pp. 1909.

Bastin, E. S. Clays of the Penobscot Bay region, Maine. In Bulletin 285, pp. 428–431. 1906.

Branner, J. C. Bibliography of clays and the ceramic arts. Bulletin 143. 114 pp. 1896. 15c.

——— The clays of Arkansas. Bulletin 351. 247 pp. 1908.

Butts, Charles. Clays of the Birmingham district, Alabama. In Bulletin 315, pp. 291–295. 1907. 50c.

Crider, A. F. Clays of western Kentucky and Tennessee. In Bulletin 285, pp. 417–427. 1906.

Darton, N. H. Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming. Professional Paper 65. 106 pp. 1909.

Darton, N. H., and Siebenthal, C. E. Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report. Bulletin 364. 81 pp. 1909.

Eckel, E. C. Stoneware and brick clays of western Tennessee and northwestern Mississippi. In Bulletin 213, pp. 382–391. 1903. 25c.

——— Clays of Garland County, Ark. In Bulletin 285, pp. 407–411. 1906.

Fenneman, N. M. Clay resources of the St. Louis district, Missouri. In Bulletin 315, pp. 315–321. 1907. 50c.

Fisher, C. A. The bentonite deposits of Wyoming. In Bulletin 260, pp. 559–563. 1905. 40c.

——— Clays in the Kootenai formation near Belt, Mont. In Bulletin 340, pp. 417–423. 1908.

Fuller, M. L. Clays of Cape Cod, Massachusetts. In Bulletin 285, pp. 432–441. 1906.

LANDES, HENRY. The clay deposits of Washington. In Bulletin 260, pp. 550–558. 1905. 40c.

LINES, E. F. Clays and shales of the Clarion quadrangle, Clarion County, Pa. In Bulletin 315, pp. 335–343. 1907. 50c.

MATSON, G. C. Notes on the clays of Florida. In Bulletin 380, pp. 346–356. 1909.

MIDDLETON, JEFFERSON. Clay-working industries. In Mineral Resources U. S. for 1908, pt. 2, pp. 455–504. 1909.[a]

PHALEN, W. C. Clay resources of northeastern Kentucky. In Bulletin 285, pp. 412–416. 1906.

——— Economic geology of the Kenova quadrangle, Kentucky, Ohio, and West Virginia. In Bulletin 349, pp. 112–122. 1908.

PHALEN, W. C., and MARTIN, LAWRENCE. Clays and shales of southwestern Cambria County, Pa. In Bulletin 315, pp. 344–354. 1907. 50c.

PORTER, J. T. Properties and tests of fuller's earth. In Bulletin 315, pp. 268–290. 1907. 50c.

RIES, H. Technology of the clay industry. In Sixteenth Ann. Rept., pt. 4, pp. 523–575. 1895. $1.20.

——— The pottery industry of the United States. In Seventeenth Ann. Rept., pt. 3, pp. 842–880. 1896.

——— The clays of the United States east of the Mississippi River. Professional Paper 11. 298 pp. 1903. 40c.

SCHRADER, F. C., and HAWORTH, E. Clay industries of the Independence quadrangle, Kansas. In Bulletin 260, pp. 546–549. 1905. 40c.

SHALER, M. K., and GARDNER, J. H. Clay deposits of the western part of the Durango-Gallup coal field of Colorado and New Mexico. In Bulletin 315, pp. 296–302. 1907. 50c.

SHALER, N. S., WOODWORTH, J. B., and MARBUT, C. F. The glacial brick clays of Rhode Island and southeastern Massachusetts. In Seventeenth Ann. Rept., pt. 1, pp. 957–1004. 1896.

SIEBENTHAL, C. E. Bentonite of the Laramie Basin, Wyoming. In Bulletin 285, pp. 445–447. 1906.

STOSE, G. W. White clays of South Mountain, Pennsylvania. In Bulletin 315, pp. 322–334. 1907. 50c.

VAN HORN, F. B. Fuller's earth. In Mineral Resources U. S. for 1907, pp. 731–734, pt. 2. 1908. $1.00.

VAUGHAN, T. W. Fuller's earth of southwestern Georgia and Florida. In Mineral Resources U. S. for 1901, pp. 922–934. 1902. 50c.

——— Fuller's earth deposits of Florida and Georgia. In Bulletin 213, pp. 392–399. 1903. 25c.

VEATCH, O. Kaolins and fire clays of central Georgia. In Bulletin 315, pp. 303–314. 1907. 50c.

WOOLSEY, L. H. Clays of the Ohio Valley in Pennsylvania. In Bulletin 225, pp. 463–480. 1904. 35c.

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[a] Previous volumes of the Mineral Resources of the United States contain chapters devoted to clay and the clay-working industries of the United States.

GYPSUM AND PLASTERS.

THE GYPSUM DEPOSITS OF THE PALEN MOUNTAINS, RIVERSIDE COUNTY, CALIFORNIA.

By E. C. Harder.

GENERAL STATEMENT.

Extensive deposits of gypsum occur in the Palen Mountains between the Colorado and Mohave deserts, in northern Riverside County, Cal. At present they are of little economic importance, being 50 miles from Parker, Ariz., and 60 miles from Danby, Cal., both on the Atchison, Topeka and Santa Fe Railway, and 70 miles from Mecca, Cal., on the Southern Pacific Railroad. The route from Mecca is the common way of approach. The new cut-off of the Santa Fe from Parker to Cadiz, Cal., now under construction, will, however, probably pass within about 15 miles of the deposits. (See fig. 33.)

The gypsum is very pure, occurring in extensive layers interbedded with limestone in a limestone, gypsum, and quartzite series. Most of it is finely crystalline and compact and varies in color from transparent white to slightly reddish. A small percentage of the material is anhydrite, finely granular and snow-white, occurring in layers and lenses in the crystalline gypsum. Both varieties contain some calcium carbonate, the anhydrite in places as much as 20 per cent. A considerable proportion of the gypsum is sufficiently compact to be used for ornamental purposes.

Some of the gypsum beds reach a thickness of a few hundred feet, with little interbedded limestone; the entire gypsum-bearing series is probably several thousand feet in thickness. In some places the gypsum is predominant, but elsewhere the limestone is by far the more abundant. Several beds of quartzite occur in the series, interlayered with limestone and locally reach a considerable thickness.

The gypsum-bearing belt is roughly about 3 miles long and from half a mile to 1½ miles wide. It runs across the Palen Mountains in a general east-west direction, disappearing under unconsolidated desert deposits on both sides. It is bounded on the north by a great mass of granite and on the south by shales and quartzites with intrusive igneous rocks of several varieties. The gypsum beds are largest and most abundant in the southern part of the belt. The strike of the beds varies between east-west and northeast-southwest; the dip is at varying angles to the north or northwest.

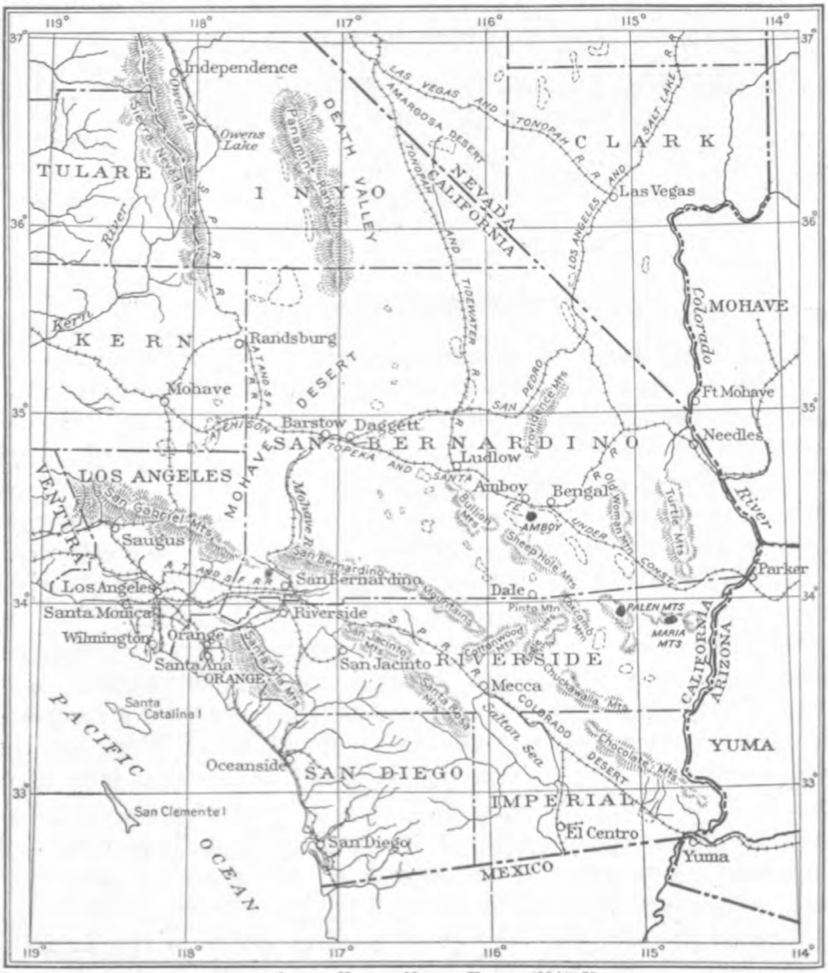

FIGURE 33.—Map showing location of known gypsum deposits in southeastern San Bernardino and Riverside counties, Cal.

A dark intrusive igneous rock occurs within the gypsum-limestone area, being especially abundant in the northern half of the belt. It cuts the gypsum beds more commonly than the limestone and quartzite because of their softer nature. On account of this fact many of the gypsum beds are locally so intricately intermixed with igneous rock as to be almost valueless. However, large portions of the area are free from these intrusive rocks.

The Palen Mountain gypsum beds are practically untouched, except for a few short tunnels that have been driven in here and there to answer the requirements for assessment work.

The gypsum and limestone of the Palen Mountains reappear 5 or 6 miles to the east from under the desert deposits and occur throughout the extent of the Maria Mountains. In the western part of these mountains limestone is predominant, but in the central part gypsum deposits of even greater extent than those in the Palen Mountains are reported to occur.

The age of the gypsum-bearing series is unknown. In general appearance, texture, and metamorphism the rocks resemble other sediments of the southeastern Mohave Desert that have generally been considered of pre-Cambrian age. The sediments of central western Arizona have been shown to be of pre-Cambrian age and to be intruded by Mesozoic granitic and dioritic rocks. Bancroft [a] and Schrader [b] have examined these rocks in Arizona and for a short distance west of Colorado River in California, to a point about 30 miles directly east of the Palen Mountains. It is supposed that they extend westward into the Mohave Desert, but they have not been correlated with the rocks of the Palen Mountains and other areas to the west.

About 50 miles north of the Palen Mountain area, near Siam, on the Santa Fe Railway, Darton [c] has found a series of sediments of Cambrian age and also sediments of probable Carboniferous age. These rocks, however, have apparently suffered no dynamic metamorphism, and in this respect are unlike the sediments of the Palen Mountains. However, the latter may be of Paleozoic age, their metamorphism being due to heat and pressure accompanying the great intrusion of granite to the north.

LOCATION AND TOPOGRAPHY.

The Palen Mountains have a general north-south direction, being about 20 miles long and of varying width. They are slightly crescent-shaped, with the opening to the west. At both ends they are high and rugged, but at the center, where crossed by the Parker-Mecca road, they are low and narrow. The southern portion of the range is much wider than the northern portion. The gypsum deposits occur in the central part of the range, south of the Parker-Mecca road.

The Palen Mountains are surrounded by broad, flat desert areas, beyond which are other mountain ranges. Like most of the ranges

[a] Bancroft, Howland, Reconnaissance of the ore deposits of central western Arizona: Bull. U. S. Geol. Survey (in preparation).

[b] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Arizona: Bull. U. S. Geol. Survey No. 397, 1909.

[c] Darton, N. H., Discovery of Cambrian rocks in southeastern California: Jour. Geology, vol. 15, 1907, pp. 470-473.

in the Mohave and Colorado deserts, they are bare of trees except along the outwash aprons bordering them, where small stunted growths of ironwood and palo verde occur sparingly. On the mountains themselves only greasewood, cacti, and a few varieties of sagebrush grow.

The only watering place in the district, with the exception of a few natural tanks along some of the canyons, is Packard's well, located in the pass near the road. Boulder well is 20 miles to the southwest, in the middle of a broad desert, and Brown's well is about 20 miles to the east. Packard's well is open, and consequently the water generally contains numerous dead bees and desert animals, which make it unfit to drink except for stock.

GENERAL GEOLOGY.

North of the gypsum-bearing series and presumably composing most of the northern half of the range is a coarsely crystalline porphyritic biotite granite, with phenocrysts of pink orthoclase. Biotite is very abundant, giving to the rock a grayish-pink color. Dikes of medium-grained pink granite or aplite cut the coarse porphyritic granite abundantly in all directions. These dikes consist largely of quartz and pink feldspar, with minor quantities of muscovite and biotite.

South of the granite mass is a belt from a quarter to half a mile wide, of low rolling hills made up of unconsolidated gravel, sand, and bowlders and extending in an east-west direction across the range.

The sedimentary rocks, consisting of limestone, gypsum, sandstone, quartzite, shale, and slate, lie south of this low belt and dip at varying angles to the north or northwest. Intrusive rocks of several varieties cut them in many places. The sediments and intrusive rocks are arranged roughly in bands trending a little south of west, with the following general succession from northwest to southeast: (1) Limestone with little interbedded gypsum, found only in the northwestern part of the area; (2) intrusive quartz-biotite diorite extending about two-thirds of the way across the range from west to east; (3) interbedded limestone and gypsum, with quartzite, fine-grained sandstone, and chert in the lower (southeastern) part. This band extends entirely across the range. The limestone and gypsum are well developed in the northeastern part, but in the southwestern part are almost entirely replaced by the quartzite, sandstone, and chert; (4) intrusive quartz-biotite diorite which is well developed in the northeastern and central parts, but gradually pinches out at the southwest end; (5) interbedded gypsum and limestone, the former the more abundant. This is the widest of the five belts and also extends entirely across the range from desert to desert. Gypsum is very abundant in its southwestern and central portions, but gives place to limestone toward the northeast; (6) interbedded green sandstones, quartzites, conglomerates, and shales. This series is wide in the southwestern part, but is cut off entirely near the northeast end by (7) a dark-gray intrusive quartz porphyry. The extent of the quartz porphyry to the south is not known, but it is presumably not great, and beyond the porphyry there may be more quartzites and slates cut by other intrusive rocks. Such a complex probably forms the southern half of the mountains, but no more limestone or gypsum occurs south of the mass of quartz porphyry. As the entire limestone-gypsum belt is only from half a mile to 1½ miles wide, it occupies but a small portion of the Palen Mountains.

The limestones are white to light brown or grayish brown in color and vary in texture from coarsely crystalline to massive and granular. Gypsum is interlayered with them, sparingly in the northern area, more abundantly in the central area, and predominantly in the southern area. The gypsum beds reach a thickness of several hundred feet, but the limestone beds, especially in the northern area, are much thicker. Between the large gypsum and limestone beds there is generally a transition zone several feet in thickness of interlayered limestone, gypsum, and anhydrite. The gypsum and anhydrite in this zone are strongly impregnated with calcium carbonate.

The northern area is predominantly limestone, with no quartzite and but few intrusive masses. Gypsum occurs in it in thin, scattered lenses of little or no importance.

The central limestone-gypsum area contains in its northern and eastern parts limestone and gypsum in about equal abundance, but in its southern and western parts it is occupied almost entirely by fine-grained quartzite and a series of interlaminated chert and limestone layers that form a row of sharp, steep-sided peaks trending northeast and southwest. The dip of the beds taken at various points along this band showed a variation between 25° and 50° NE.; the strike varies from N. 55° E. to east-west.

Intrusive sheets or irregular masses of quartz-mica diorite occur abundantly in all the rocks, and locally contact minerals are developed, especially near the contact with limestone or laminated limestone and chert strata. The metamorphic minerals are mostly garnet, epidote, hornblende, and quartz. Small deposits of iron ore, consisting of magnetite, hematite, and limonite intermixed, occur in several places at the limestone and diorite or quartzite and diorite contacts. At some places serpentine is present in small quantities in the limestone, and locally it is concentrated along the diorite contact in association with the iron ore. Tremolite, chlorite (penninite), selenite, dolomite, calcite, pyrite, and copper sulphides also occur with the iron-ore masses, but they contain no garnet or epidote. Small veins of green asbestos are found in the serpentine along the diorite contact, and bunches of soft white asbestos are associated with serpentine locally along the contact of limestone and gypsum beds. The intrusive bodies of diorite in the gypsum vary from large irregular masses to small ramifying dikes less than an inch in thickness; those in the other formations are generally massive and regular. The gypsum has been intruded abundantly by networks of dikes because of its easy access. Apparently the intrusions have had little or no effect on the gypsum at the contact except local pulverizing and probably dehydration.

The southern limestone-gypsum belt is occupied largely by gypsum in the southwestern and central parts but contains much limestone in the northeastern part. The limestone layers, being harder than the gypsum, stand above it in ridges and peaks, whereas the gypsum forms smooth, gradual slopes. A lens of quartzite divides the limestone-gypsum belt into two portions in the eastern part of the area. Small intrusions of diorite occur locally, though they are much less abundant than in the central belt. The dip of the beds averages about 40° NW.; the strike varies between N. 65° E. and N. 80° E.

The quartz-biotite diorite is intrusive into the gypsum-bearing series, occurring chiefly in the two large areas which separate the central limestone-gypsum belt from the northern and southern belts, but also as small scattered masses within the central and southern areas and in the shale beds to the south. The rock varies much in texture and general appearance in the different areas and in different parts of the same area. However, one phase grades into another and the mineral constituents are much the same throughout.

The minerals composing the diorite are largely plagioclase feldspar, quartz, and biotite. In some places the biotite is very abundant and the rock is dark and rather schistose; elsewhere the feldspar and quartz predominate, making the rock light colored and foliated rather than schistose. The rock is fine grained, containing small phenocrysts of feldspar sparingly in some places and abundantly in others. In the light-colored phases fine flakes of biotite are in places segregated into bunches arranged along definite lines, thus producing the foliation. Locally areas of biotite diorite are strongly epidotized and contain numerous veins of epidote. Some small masses consist entirely of hornblende and epidote. Quartz veins are characteristic of all the intrusive masses. Some of them are clean cut; others occur as large irregular masses in brecciated zones. Copper sulphides and stains of copper carbonate are found in many of these veins.

The shales, quartzites, and slates bounding the limestone-gypsum area on the south are of a prevailing green color. They are compact and fine grained for the most part, but are interlayered with extensive beds of conglomerate. The succession southward from the limestone-gypsum belt is: (1) A great thickness of green and gray shales and slates, intruded by black schistose quartz-biotite diorite; (2) fine-grained green quartzite and conglomerate.

The quartz porphyry is intruded into these rocks at an angle to the bedding, so that toward the northeast it cuts out the quartzite and conglomerate beds and then the shale and slate beds, coming directly into contact with the limestone in the eastern part of the area. The quartz porphyry is a dense, compact rock with a dark-gray fine-grained groundmass in which are scattered phenocrysts of fresh, glassy quartz and feldspar.

STRUCTURE AND ORIGIN OF THE GYPSUM BEDS.

Gypsum deposits have been divided by Hess[a] into four main types—(1) efflorescent deposits, (2) periodic-lake deposits, (3) interbedded deposits, and (4) veins.

Efflorescent deposits are formed by the evaporation of water that has percolated through gypsiferous sandstones and shales. These are surface deposits and most of them lie on the tops of hills and ridges. They are thin and rather narrow, though some of them are 10 or 15 feet thick and have an area of several acres. This gypsum is of the variety gypsite. It is buff to creamy or rust colored, soft, and easily crumbled in the hands. Some of it is powdery and resembles ashes, though under the microscope all of it is seen to consist of small crystalline scales.

Periodic-lake deposits are formed by the crystallization of gypsum from the saturated waters of intermittent shallow lakes. They occur as beds in alkali or dry lake flats and are in many places covered by several feet of soil. The gypsum is generally granular and crystalline, the particles ranging in size from minute specks to scales a quarter of an inch in breadth.

Interbedded deposits are of two principal varieties, one consisting of thin beds of impure gypsum from a fraction of an inch to 3 or 4 inches thick, interstratified with clayey material, and the other of beds of pure gypsum ranging up to many feet in thickness, interlayered with limestone or other sediments. The deposits of the first variety were probably formed by precipitation in a shallow sea into which large quantities of sediments were being poured; those of the second were laid down in deep water under more constant conditions of saturation.

Gypsum veins consist of the transparent crystalline variety of gypsum known as selenite, or in a few places of the columnar variety known as satin spar. They are formed by the solution of gypsum

[a] Hess, F. L., A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910, pp. 7-8.

from the surrounding rocks or from other deposits and its redeposition in cracks.

The Palen Mountain gypsum beds belong to the second variety of interbedded deposits. In detail they consist largely of finely crystalline selenite in flakes varying up to one-tenth of an inch or more in diameter. The individual flakes are transparent and colorless, but in aggregates they are white or slightly cream-colored. At a few localities the gypsum has a beautiful orange-red tint.

Interlayered with the crystalline gypsum, but much less abundant and apparently only local in its occurrence, is a finely granular snow-white mixture of anhydrite and calcium carbonate. It is found in lenses varying up to several feet in diameter within the selenite and also in the transition zones between large limestone and gypsum beds. The contact between the granular and the crystalline material is generally sharp. However, small bunches of selenite are scattered through the anhydrite lenses and small bunches of anhydrite occur in the selenite beds. The contact of the larger gypsum and limestone beds is generally marked by a transitional zone, consisting of interlayered calcium sulphate and limestone. The calcium sulphate in this zone is largely anhydrite and has considerable calcium carbonate intermixed with it, and the limestone probably contains some calcium sulphate. Layers of limestone, varying down to less than half an inch in thickness, occur in the anhydrite near the base or top of the larger gypsum beds, and similarly thin layers of anhydrite occur in limestone near the borders of the main limestone layers. The contact between these thin layers and the inclosing rock is everywhere sharp, showing a succession of changes in deposition. Such transition zones between the main beds are locally 6 feet or more in thickness.

In some places gypsum beds of great thickness occur with little or no interbedded limestone; in others there are great thicknesses of limestone without gypsum. Commonly, however, the deposits alternate in layers varying from less than a foot to 40 or 50 feet in thickness. In some places thin beds of limestone occur between thick gypsum beds; elsewhere thin beds of gypsum are found between heavy beds of limestone.

Most of the crystalline gypsum contains a small percentage of calcium carbonate and the granular mixture of anhydrite and calcium carbonate may contain as high as 20 per cent of it. As the granular material, however, makes up but a small proportion of the beds, by far the larger part of the gypsum is fairly pure. The following partial chemical analyses represent picked samples of the crystalline gypsum and the granular mixture of anhydrite and calcium carbonate:

Chemical analyses of gypsum and of anhydrite and calcium carbonate from the Palen Mountains.

[George Steiger, analyst.]

	Crystalline gypsum.	Anhydrite and calcium carbonate.
CaO	32.55	37.13
H_2O-	.03	.04
H_2O+	18.23	1.27
CO_2	6.03	17.57
SO_3	41.47	37.15
	98.31	93.16
Undetermined (MgO, Cl., etc.)	1.69	6.84

The mineral composition of the gypsum and anhydrite, calculated from the preceding chemical analyses, is as follows:

Mineral composition of gypsum and of anhydrite and calcium carbonate from the Palen Mountains.

	Crystalline gypsum.	Anhydrite and calcium carbonate.
Gypsum	87.31	6.27
Anhydrite	1.31	58.21
Calcite	6.53	19.84
Surplus CO_2	3.16	8.84
	98.31	93.16
Undetermined	1.69	6.84

In making these calculations all the H_2O present is assumed to be combined with the requisite quantities of CaO and SO_3 to form gypsum. Water of combination and uncombined water are added together, because it is difficult to distinguish between them in gypsum analyses. The surplus SO_3 is then combined with the CaO necessary to form anhydrite, after which the surplus CaO is combined with enough CO_2 to form calcite. The CO_2 remaining after these calculations may be assumed to be combined with the undetermined constituents in the form of carbonates. In both analyses, however, even if the most favorable condition is assumed, namely, that all the undetermined material is MgO, there is still some surplus CO_2 after the formation of $MgCO_3$. This fact shows that besides the calcium sulphates other sulphates must be present in which the proportion of SO_3 to the base is greater than in the calcium sulphates, thus leaving a greater proportion of CaO and other bases for combination with the surplus CO_2. It is also possible that not all the H_2O is combined in the form of gypsum and that there are compounds of intermediate hydration between gypsum and anhydrite in which the proportion of SO_3 to CaO is greater than in gypsum. Some chlorides are also undoubtedly present.

From the occurrence of the gypsum in beds alternating with layers of limestone there seems little doubt that it was formed as an original deposit from supersaturated waters. The formation of the white granular mixture of anhydrite and calcium carbonate that occurs in lenses within the selenite beds and at their contact with the limestone is due to an original difference in composition. The occurrence of this mixture in the contact zone between the limestone and gypsum beds shows a gradual transition from the deposition of one to that of the other. After the consolidation of the beds regional folding and metamorphism took place, altering the limestone locally to a coarse marble and the gypsum widely to selenite. Later occurred the intrusion of the diorite, which broke through the selenite in many places, partly dehydrated it here and there along the contacts, and changed it from crystalline rock to a friable white powder.

GYPSUM DEPOSITS NEAR CANE SPRINGS, KERN COUNTY, CALIFORNIA.

By Frank L. Hess.

About 3½ miles southeast of Cane Springs, Cal., on the new line of the Southern Pacific Railroad joining Mohave and Keeler, gypsite deposits of some extent were discovered in the fall of 1909. The area is in the Mohave Desert, about 30 miles northeast of Mohave, in a fault valley of a type common to the desert. This valley has no outlet and receives the water of the intermittent streams that flow from the surrounding mountains and form a periodic lake or playa. No perennial streams discharge into the basin, but at times heavy storms cause the intermittent streams to flow so that the lake bed is covered to a depth of 1 or 2 feet. The valley is probably 7 or 8 miles wide and 25 miles long.

On the south and east the valley is bordered by old crystalline rocks, granites, and schists. On the north and west lie the Nugget and El Paso mountains, which are composed of old crystalline and effusive rocks, Tertiary sandstones, and older sedimentary strata, including both limestone and fragmental rocks. No rocks in place are exposed in the valley except at the edge of the débris on either side. The valley is deeply filled with detritus, which is shown by borings to be more than 800 feet deep and is finer toward the center of the valley. The lake bed, about 5 by 8 miles in extent, is covered with a fine mud. On the northeast side of the lake the valley floor consists of sand, but on the southwest it is made up of silt similar to that of the lake bed. It is probable that the land on the south was once covered by the lake and that the lake's position has been moved owing to the unequal lowering of the present bed by faulting.

The gypsite deposits, so far as known, are located on the south edge of the present playa, in what was possibly its former bed, on a slope which rises gently to the southwest. The gypsite is exceedingly fine grained, of a buff color, and is exposed at the surface over an area covering nearly a section. A grass called saccaton grows over the entire area and its roots sink into the gypsite. The thickest beds lie in the SE. ¼ NW. ¼ sec. 28, T. 30 S., R. 38 E., Mount Diablo base and meridian, and reach a depth of 10 feet, occupying the higher ground between the shallow stream beds leading to the lake. In places the streams have dissolved the gypsite and left small sinks similar to those in a limestone country. In the lower places the gypsite is thin, at many points being not more than 1 or 2 feet thick. Here and there the gypsite is somewhat mixed with clay; in other places the clay has flowed over the gypsite at times of high water, and this process has been repeated, so that several layers of clay are intercalated with the gypsite.

There is an efflorescence of sodium carbonate and sodium sulphate on the surface, but it forms no considerable impurity in the gypsite.

The gypsite becomes thinner and gives out entirely where the damp earth of the lake bed is reached, so far as present exploitation shows. The ground beneath the gypsite is apparently made up of alternating beds of clays, sands, and gravels, and the gypsite is probably formed by efflorescence from these materials.

A partial analysis of a specimen collected where prospect holes showed the gypsum to be thickest is as follows:

Partial analysis of gypsite from the deposit 3½ miles southeast of Cane Springs, Kern County, Cal.

[George Steiger, analyst.]

Lime (CaO)	28.76
Sulphur trioxide (SO_3)	37.06
Carbon dioxide (CO_2)	1.87
Water driven off at 60° C.	.78
Water driven off at 300° C.	17.30
Chlorine (Cl)	Trace.
Iron oxide (Fe_2O_3)	.71

This shows an equivalent of about 79.5 per cent of gypsum. The most striking item in the analysis is an excess of water, which is probably present in clay. Some lime carbonate is present. The iron is low. Salt had been reported as present, but in the sample collected there was too small a quantity to weigh. There seem to be no elements present which would be detrimental in the manufacture of plaster. The clay would probably make it leave the trowel better than if it were not present.

On the north side of the gypsite deposits is an artesian well with a small flow of very good water. The depth of the well was not learned but is supposed to be more than 100 feet. The water is slightly impregnated with hydrogen sulphide (H_2S), which may possibly come from the alteration of gypsum.

SURVEY PUBLICATIONS ON GYPSUM AND PLASTERS.

The more important publications of the United States Geological Survey on gypsum and plasters are included in the following list. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ADAMS, G. I., and others. Gypsum deposits of the United States. Bulletin 223. 123 pp. 1904. 25c.

BOUTWELL, J. M. Rock gypsum at Nephi, Utah. In Bulletin 225, pp. 483–487. 1904. 35c.

BURCHARD, E. F. Gypsum and gypsum products. In Mineral Resources U. S. for 1908, pt. 2, pp. 621–627. 1909.

DARTON, N. H., and SIEBENTHAL, C. E. Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report. Bulletin 364. 81 pp. 1909.

ECKEL, E. C. Gypsum and gypsum products. In Mineral Resources U. S. for 1905, pp. 1105–1115. 1906. $1.

HESS, F. L. A reconnaissance of the gypsum deposits of California. Bulletin 413. 37 pp. 1910.

RICHARDSON, G. B. Salt, gypsum, and petroleum in trans-Pecos Texas. In Bulletin 260, pp. 573–585. 1905. 40c.

SHALER, M. K. Gypsum in northwestern New Mexico. In Bulletin 315, pp. 260–265. 1907. 50c.

SIEBENTHAL, C. E. Gypsum of the Uncompahgre region, Colorado. In Bulletin 285, pp. 401–403. 1906. 60c.

——— Gypsum deposits of the Laramie district, Wyoming. In Bulletin 285, pp. 404–405. 1906. 60c.

LIME AND MAGNESITE.

SURVEY PUBLICATIONS ON LIME AND MAGNESITE.

In addition to the papers listed below, which deal principally with lime, magnesite, etc., further references on limestones will be found in the lists given under the heads "Cement" and "Building stone." These publications, except the one to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BASTIN, E. S. The lime industry of Knox County, Me. In Bulletin 285, pp. 393–400. 1906. 60c.

BURCHARD, E. F., BUTTS, CHARLES, and ECKEL, E. C. Iron ores, fuels, and fluxes of the Birmingham district, Alabama. Bulletin 400. 204 pp. 1910.

BUTTS, CHARLES. Limestone and dolomite in the Birmingham district, Alabama. In Bulletin 315, pp. 247–255. 1907.

CALKINS, F. C., and MACDONALD, D. F. A geologic reconnaissance in northern Idaho and northwestern Montana. Bulletin 384. 112 pp. 1909.

COONS, A. T. Lime. In Mineral Resources U. S. for 1908, pt. 2, pp. 511–515. 1909.

HESS, F. L. Some magnesite deposits of California. In Bulletin 285, pp. 385–392. 1906. 60c.

——— The magnesite deposits of California. Bulletin 355. 67 pp. 1908.

RIES, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. In Seventeenth Ann. Rept., pt. 3, pp. 795–811. 1896.

YALE, C. G. Magnesite. In Mineral Resources U. S. for 1908, pt. 2, pp. 739–741, 1909.

GLASS SAND, ETC.

SURVEY PUBLICATIONS ON GLASS SAND AND GLASS-MAKING MATERIALS.

The list below includes the important publications of the United States Geological Survey on glass sand and glass-making materials. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BURCHARD, E. F. Requirements of sand and limestone for glass making. In Bulletin 285, pp. 452–458. 1906.

—— Glass sand of the middle Mississippi basin. In Bulletin 285, pp. 459–472. 1906.

—— Glass-sand industry of Indiana, Kentucky, and Ohio. In Bulletin 315, pp. 361–376. 1907.

—— Notes on glass sands from various localities, mainly undeveloped. In Bulletin 315, pp. 377–382. 1907.

FENNEMAN, N. M. Geology and mineral resources of the St. Louis quadrangle. Bulletin 438 (in preparation).

STOSE, G. W. Glass-sand industry in eastern West Virginia. In Bulletin 285, pp. 473–475. 1906.

WEEKS, J. D. Glass materials. In Mineral Resources U. S. for 1883–1884, pp. 958–973. 1885. 60c.

—— Glass materials. In Mineral Resources U. S. for 1885, pp. 544–555. 1886. 40c.

ABRASIVES.

SURVEY PUBLICATIONS ON ABRASIVE MATERIALS.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various abrasive materials. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The one marked "Exhausted" is not available for distribution, but may be seen at the larger libraries of the country.

ARNOLD, RALPH, and ANDERSON, ROBERT. Diatomaceous deposits of northern Santa Barbara County, Cal. In Bulletin 315, pp. 438–447. 1907. 50c.

CHATARD, T. M. Corundum and emery. In Mineral Resources U. S. for 1883–84, pp. 714–720. 1885. 60c.

ECKEL, E. C. The emery deposits of Westchester County, N. Y. In Mineral Industry, vol. 9, pp. 15–17. 1901.

HOLMES, J. A. Corundum deposits of the southern Appalachian region. In Seventeenth Ann. Rept., pt. 3, pp. 935–943. 1896.

JENKS, C. N. The manufacture and use of corundum. In Seventeenth Ann. Rept. pt. 3, pp. 943–947. 1896.

PARKER, E. W. Abrasive materials. In Nineteenth Ann. Rept., pt. 6, pp. 515–533. 1898.

PHALEN, W. C. Abrasive materials. In Mineral Resources U. S. for 1908, pt. 2, pp. 581–598. 1909.

PRATT, J. H. The occurrence and distribution of corundum in the United States. Bulletin 180. 98 pp. 1901. 20c.

——— Corundum and its occurrence and distribution in the United States. Bulletin 269. 175 pp. 1905. (Bulletin 269 is a later and revised edition of Bulletin 180.)

RABORG, W. A. Buhrstones. In Mineral Resources U. S. for 1886, pp. 581–582. 1887. 50c.

——— Grindstones. In Mineral Resources U. S. for 1886, pp. 582–585. 1887. 50c.

——— Corundum. In Mineral Resourses U. S. for 1886, pp. 585–586. 1887. 50c.

READ, M. C. Berea grit. In Mineral Resources U. S. for 1882, pp. 478–479. 1883. 50c.

SIEBENTHAL, C. E., and MESLER, R. D. Tripoli deposits near Seneca, Mo. In Bulletin 340, pp. 429–437. 1908.

TURNER, G. M. Novaculite. In Mineral Resources U. S. for 1885, pp. 433–436. 1886. 40c.

——— Novaculites and other whetstones. In Mineral Resources U. S. for 1886, pp. 589–594. 1887. 50c.

WOOLSEY, L. H. Volcanic ash near Durango, Colo. In Bulletin 285, pp. 476–479. 1906. 60c.

MINERAL PAINTS.

INTRODUCTORY NOTE.

During the spring of 1909 field and laboratory studies of two important classes of mineral-paint materials were carried on by the Survey in eastern Pennsylvania under the general direction of Ernest F. Burchard. The work was done by four senior students in mining engineering at Lehigh University and was closely supervised by B. L. Miller, professor of geology at Lehigh. J. C. Stoddard and A. C. Callen studied the ocher deposits between Reading and Allentown, and F. T. Agthe and J. L. Dynan studied the paint-ore deposits near Lehigh Gap. The papers, substantially as published below, were accepted as theses for the degree of engineer of mines at Lehigh University in June, 1909, and an abstract of each was published by the Survey shortly afterward.[a]

[a] Burchard, E. F., Production of mineral paints in 1908: Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909, pt. 2, pp. 679-687.

OCHER DEPOSITS OF EASTERN PENNSYLVANIA.

By Jesse C. Stoddard and Alfred C. Callen.

ALLENTOWN-READING DISTRICT.

GEOGRAPHY.

The principal ocher belt in Pennsylvania is a comparatively narrow strip extending from Reading to Allentown and approximately following the line of the East Pennsylvania branch of the Philadelphia and Reading Railroad. The district is comprised in the Reading, Slatington, and Allentown quadrangles of the United States Geological Survey and lies in the counties of Berks and Lehigh.

The East Pennsylvania branch furnishes convenient transportation facilities. It passes through the center of the belt and reduces the teaming distance for most of the deposit to less than 1 mile. The roads of the section are very good and the cost of haulage to the shipping point is a small item.

Physiographically, the ocher belt lies at the northern base of the chain of hills designated the Durham and Reading hills in the reports of the Pennsylvania Geological Survey. From the base of these hills the region passes into a low-lying, level limestone valley well drained by numerous streams tributary to Schuylkill and Lehigh rivers.

HISTORY.

Little accurate information is available on the history of the ocher-mining industry, but in general it may be said that the discovery and subsequent working of the deposits were due to the former rather extensive prospects and operations on the local iron ore, which is invariably found above and in intimate association with the ocher. In one of the mines visited the remains of the old drifts and shafts, formerly used in mining iron ore, were encountered, showing the extent to which the iron mining was carried on. The history of each mine will be taken up in the detailed description of the mines.

DEVELOPMENTS.

Owing to the minor importance of the industry and its intermittent operation consequent on the conditions of the market, none of the mines and plants visited have attained any advanced stage of development. On the contrary, the prevalent conditions are primitive, little capital has been invested, and no extensive improvements have been installed. In the spring of 1909 most of the mines were in a dilapidated condition and were either filled with water or squeezed together and caved in as a result of their temporary abandonment for the winter and early spring. For this reason personal examination and study of all the underground workings was impossible and a large amount of the information herein contained was necessarily derived from surface observations and from persons familiar with the mines and the ocher industry.

The mining equipment, including hoisting apparatus, tramming, etc., and the facilities for preparing the ocher for shipment vary little throughout the region. Power is obtained from a small steam plant which operates the mine pumps, hoisting apparatus, washing plant, and grinding machinery in cases where the ocher is given its final treatment at the locality where it is mined. The Cornish pumps, the log washer, and the wheelbarrow are the typical devices employed for pumping, washing the ocher free from the larger particles it contains, and underground tramming.

GEOLOGY.

DISTRIBUTION OF ROCKS.

The rocks of this district, in the order of their formation, are the pre-Cambrian gneiss, the Chickies quartzite (of Cambrian age), and the Shenandoah limestone (of Cambro-Ordovician age).

The gneiss, known locally as the South Mountain gneiss, is highly metamorphosed and has a granitic texture. In a small hand specimen, where the banding is not apparent, it might be mistaken for a granite. It is mainly basic, but in some places it is highly acidic. The acidic phase of the rock weathers easily, decays in place, and forms sand deposits which are worked in many places. The gneiss varies in color from a greenish black to light green. The most common minerals as determined from the hand specimen and under the microscope are quartz, orthoclase, plagioclase, hornblende, biotite, chlorite, and magnetite. The gneiss forms the main mass of the Reading and Durham hills and its width of outcrop varies from 1 to 5 miles.

Above the gneiss and lying unconformably upon it is the Chickies quartzite (formerly called the Potsdam), which varies from a fine to a coarse grained sandstone and in some places, especially near the base, contains layers of quartz pebbles. The grains are rounded and bound together by a siliceous cement. The color of the rock varies from light gray to almost brick-red, the coloring matter, iron oxide, being practically confined entirely to the cementing material. The rock is largely used locally as a building stone. This formation outcrops in a narrow belt, usually less than a mile in width, extending along the base of the hills, and in a few isolated places in the Shenandoah limestone. *Scolithus linearis* is the characteristic fossil of the formation and is found in great abundance in the vicinity of Fleetwood.

Resting conformably upon the Chickies quartzite is the Shenandoah limestone, which is mainly an impure dolomitic limestone characterized by the presence of small lenses of chert near the base. It is oolitic in places and in some localities contains excellent ripple marks. It varies in color from a very dark gray through a bluish gray almost to white. Well-preserved fossils are very rare, *Cryptozoon* being practically the only form found. The limestone forms the floors of the valleys and is very widely distributed throughout the region. It is used as ballast and as road metal and is burned for lime.

ORE DEPOSITS.

The deposits of ocher in the Reading-Allentown district may be called residual, inasmuch as all evidence indicates that they were formed by the oxide of iron left on the decomposition of the Shenandoah limestone.

The only ore minerals present here are the nodules and geodes of limonite. The gangue material is chiefly clay, in which the ocher occurs in irregular masses. The clay is moist and plastic and varies in color from white to brown, some even being reddish and purplish. These clays are the result of the weathering of intercalated hydromica slates, which occur in association with the Cambro-Ordovician limestone and with the Cambrian quartzite. Besides the "ore minerals" there are also present small quantities of turgite, ilmenite, siderite, and pyrite. In the black clay at Breinigsville there is considerable pyrite, and a small spring near the shaft smells strongly of sulphureted hydrogen.

OCHER DEPOSITS.

As ordinarily used the term "ocher" is applied to the earthy and pulverulent forms of the minerals hematite and limonite. It is always rendered more or less impure through the presence of other metallic oxides and of argillaceous or clayey material. Limonite ochers are the only ones referred to in this report. Natural ochers show a variety of colors, which depend on the chemical composition, in general. Hematites give red ochers, and limonites give yellow, buff, or brown. The amount and kind of impurities also influence the color. In brief, the natural color of ocher depends on the degree of hydration and oxidation and the kind and quantity of impurities. As the color of ocher depends mainly on the degree of hydration, a red ocher can be made by calcining common yellow ocher.

The ocher occurs in irregular masses in the clay. At the Keystone Ocher Company's mine at Fleetwood there was evidence of stratification in the clay and ocher. Some of the masses are large and can easily be worked for high-grade ocher, but many of them are simply small pockets, which can be used only for second or third grade on account of the large amount of clay which must be mined with the ocher. Most of this clay is so fine that it can not be separated by washing and settling and so lowers the quality of the finished product. As a rule there is a considerable thickness of clay above the rock. A well boring at Fleetwood gave over 250 feet of clay, below which a bed reported to be unconsolidated gravel was struck, which could not be penetrated by the drill.

From the general evidence it appears that ocher deposits may be derived from any part of the Shenandoah limestone. There is little regularity in the occurrence of the ore, owing to the complexity of the folding of the original rocks. If there were a definite strike and dip to the beds of limestone in large areas, or if there were intercalated shale or sandstone beds, there would probably be a consequent alignment of the deposits due to concentration at these points. But such are not the conditions in this region.

ORIGIN OF THE OCHER.

To explain the origin of the ocher satisfactorily we must first give a reasonable explanation regarding the source of the iron. According to Hopkins,[a] the possible sources of iron in this district are:

1. The Lower Cambrian slate, where it occurs as the sulphide and silicate.
2. The Cambro-Ordovician limestone, where it exists as diffused carbonate, silicate, and sulphide.
3. The overlying Ordovician and Silurian shale and slate, where it occurs as carbonate, sulphide, and hydroxide.

It is a well-known fact that nearly all strata contain some iron, and so it is probable that all the above possible sources have contributed to the iron content of the ore deposits. The amount of iron furnished was not necessarily proportional to the iron content of the strata; the manner of erosion was probably the controlling feature. Sandstones and shales are largely eroded by mechanical means, and so any residual iron material would be washed away as sediment with the

[a] Hopkins, T. C., Bull. Geol. Soc. America, vol. 11, 1900, p. 490.

quartz grains, and not be concentrated. Limestones, on the contrary, are removed mainly by solution, and so the limestones are the most favorable source, as the insoluble content is left behind as a residue. This is the principal reason for believing the Shenandoah limestone to have furnished most of the ore.

Though it is believed by the authors that the limestone was the main source of the iron, yet it must be admitted that there is evidence pointing to the overlying shale and slate as a partial source. These overlying rocks contain iron, and meteoric waters containing organic acids could leach out the iron. The spring at the mine near Breinigsville was evidently seepage from the shale and was impregnated with iron. But, though it be admitted that the shale and slate furnished some of the iron, it it highly improbable that such iron formed any considerable part of the total. As is well known, shales are impervious and would naturally turn the water away from the limestone where the topography permitted. Besides, the greatest number of the deposits are found near the base of the limestone, only the one at Breinigsville being near the shales. And, as was noted before, the erosion of shales is largely mechanical, and their disintegrated material would all be washed away together.

The reasons for believing the Cambro-Ordovician limestone to be the chief source of the iron are the great number and the wide distribution of deposits on the limestone; the manner of erosion of the limestone (by solution); the commingling of the ocher with residual clay and cherty fragments characteristic of these limestones; and the fact that the limestones carry iron—a small percentage, but large enough on concentration to account for the deposits. If the limestone was the original source of the iron the processes by which it was concentrated may have been as follows. The first step is solution. Oxygenated waters acting on pyrite would decompose it, taking the iron into solution as $FeSO_4$. Iron carbonate is soluble in all acidulated waters, and as meteoric waters nearly always carry an acid the solution of the carbonate would be possible. Ferric oxide is quite insoluble as such, but is reducible by organic acids to ferrous oxide, which is easily soluble. In short, meteoric waters reduce, dissolve, and transport the iron. The next step is precipitation, and this is generally caused by oxidation and chemical reaction. The iron may be precipitated as the carbonate, as the hydroxide, or as one of the organic salts, but it is shortly brought to the stable form of the hydroxide.

The precipitation may take place at varying distances from the original source of the iron. It is probable that in the limestone area none of the solutions have been transported very far, because the water would become more and more saturated with lime, and as lime is more soluble than the iron oxide the iron would be precipitated. Deposition has taken place in a number of modes. Much of the iron has formed limonite and has been deposited in caverns, in crevices between loose rock material, in seams in limestone, and at the contact of the limestone with an underlying insoluble layer. Interstratified clay and sand beds aid in concentration by forming alternations of pervious and impervious layers, between which the limonite and ocher may collect from the overlying limestone. The segregating of the oxide may be continued in the residual clays, but less actively than in the orignial beds.

AGE OF THE DEPOSITS.

The age of the original sources of the iron is considered to be Cambrian and Ordovician. However, it is to be emphasized that the deposits themselves are residual deposits, and are *on* and not *in* the rocks of these ages. According to Hopkins, all these deposits have been formed since the uplift of the beds in late Permian or post-Permian time; also the process of formation is going on at present and has been presumably more or less continuous since Carboniferous time.

DETAILED DESCRIPTION OF MINES.

READING PLANT OF THE KEYSTONE OCHER COMPANY.

The Reading plant of the Keystone Ocher Company is situated 1 mile northwest of Reading, Pa., and one-half mile west of the Pennsylvania and the Philadelphia and Reading railroads.

When visited, the plant was not in operation and the underground workings could not be determined.

The equipment consists of a boiler and engine house, a log washer, settling boxes and tanks, a drying shed, and a roasting furnace. The deposit is opened up through four shafts varying in depth from 30 to 65 feet, the ocher being stoped out and hoisted to the surface by a windlass operated by hand. It is then wheeled to the log washer, the larger particles of impurities and foreign matter are separated out, and the fine material is passed into the troughs. Well water is fed to the washer by a perforated pipe running longitudinally along the washer, which is so arranged as to uniformly distribute the flow over the whole length of the log. After the water has been used to float off the ocher it is drained back into the well, which otherwise would be of insufficient capacity to operate the plant.

As the finely divided particles of ocher and foreign material are carried down the troughs, the heavier particles begin to settle out, the current being retarded by baffle boards, behind which the heavier particles collect. Three settling boxes, placed at intervals along the line of troughs, further retard the flow of material and cause more of the foreign particles to settle out, until the final floating is accomplished in the settling troughs. These are board troughs 1 foot square in cross section and 15 feet long, which are so arranged as to almost entirely stop the flow and enable the remaining impurities to settle to the bottom.

The mixture from the troughs is then run into the large settling tanks, 25 by 18 by 3½ feet deep, which are provided with tap holes at different levels, so that the ocher of different degrees of fineness can be drawn out as desired and left to dry until it can be shoveled and put in the drying shed. The shed is 70 feet long and 10 feet wide. There were eight shelves placed 10 inches apart vertically.

The finished material at this plant is of a golden-brown color and is called a sienna. The highest grade runs from 68 to 72 per cent Fe_2O_3. It can be burned on the premises when the demand calls for it, but the greater part of it is put on the market after being ground.

The occurrence of the ocher accords with the general conditions throughout the region, as described elsewhere in this report. It is found in pockets of different size in the clay which immediately overlies the limestone. Limonite nodules are very common.

WADE PROPERTY AT BLANDON.

E. B. Wade's property is one-half mile due south of Blandon and is at present being worked only for clay, which is shipped and refined mostly for use in iron works.

The only evidences of ocher are a few very shallow pits immediately south of the clay pits. Some ocher was formerly extracted from these pits and is said to have been of very high grade, but from all accounts none has been shipped for five years or more, and no considerable quantities were ever shipped. The clay was also formerly refined for certain kinds of paints and is said to have brought $7.50 a ton.

The deposit here lies upon the quartzite, and clays are found from 30 to 50 feet thick overlain by 8 to 10 feet of soil. The clay varies widely in color and texture, the pure-white layers being found on top in moderate quantities. It is said to be useful as an oilcloth base, as a wall-paper base, and for paint. The locality is only in the first stages of development, however, and the extent of its resources, if it has any, is unknown.

FLEETWOOD PLANT OF THE KEYSTONE OCHER COMPANY.

The Fleetwood plant of the Keystone Ocher Company is the only one, besides the adjoining plant of C. K. Williams, which was in active operation when visited. It lies 1¼ miles northeast of Fleetwood, Pa., and three-eighths of a mile from the Philadelphia and Reading Railway. The product of both of the plants is hauled in wagons to the railroad.

The deposit is opened up through two shafts within 60 feet of each other, one being used as a hoisting and pump shaft and the other as an air and timber shaft. The former is 70 feet deep and extends down to the lower level, from which all the ocher is hoisted. The method of carrying on the underground work is to drift along and follow the pockets and stringers of ocher, mining them out in stopes or breasts, and then to drift indefinitely until other deposits are found.

The accompanying plan (fig. 34) shows the approximate layout of the underground workings. The drifts or gangways are 6 to 7 feet high and 5 feet wide, being provided with four-piece round timbering to resist the squeezing action of the clay. Lagging of sawed slabs is laid close on the tops and sides, and the bottom is plank floored for the passage of wheelbarrows. Chutes are provided, as shown (fig. 34), for dumping the ocher from the upper to the lower level, whence it is wheeled to the shaft and hoisted. The stopes are turned off where

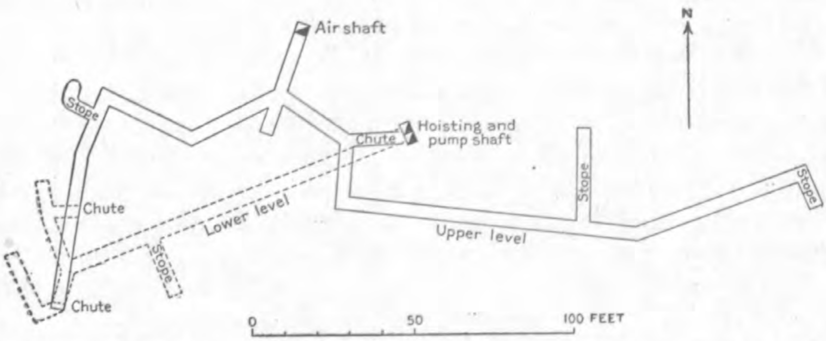

FIGURE 34.—Plan of underground workings of Keystone Ocher Company, Fleetwood, Pa.

pockets are encountered, and if their size demands it they are timbered up with square sets.

The ocher occurs either as small masses in pockets in the clay, or interstratified with the clay, as shown in the accompanying sketches (fig. 35). It is separated by hand from the clay in the mine, and the clay is used to fill up the old workings. The impurities in the ocher are particles of quartzite, cherty limestone, flakes of shaly limestone, and fragments and nodules of limonite. The limonite is picked out on the surface and is saved until a sufficient quantity for shipment has accumulated. No bed rock has been encountered in the mine workings, but a well drilled down the hoisting shaft struck loose bowlders of sandstone at 257 feet, which prevented drilling deeper.

The method of treating the ocher for the market is essentially the same as the methods previously described for the Reading plant, but the equipment is more complete.

The ocher is hoisted from the mine by an engine hoist and then dumped into a log washer, from which it passes to a series of 28 floating troughs. These troughs are 14 to 16 feet long and 13 inches square in cross section. The fine sand is separated out in the first 12 or 13 troughs, and the final separation is accomplished in the smaller set of 15, after which the mixture is run through a long trough to the settling ponds. Here it is left to partly dry as a preliminary to its transfer to the drying sheds.

After it has thoroughly dried in the sheds it is ground in French buhr mills as the final treatment for the market.

The best sienna from this plant brings from $30 to $40 per ton, and the washed ocher brings $15 to $18 per ton.

The land is usually leased for a period of fifteen or twenty years, one year or six months being allowed for exploration before the lease is executed finally. A royalty is paid to the owner either at a nominal rate or according to the amount of ocher taken out at a fixed price per ton.

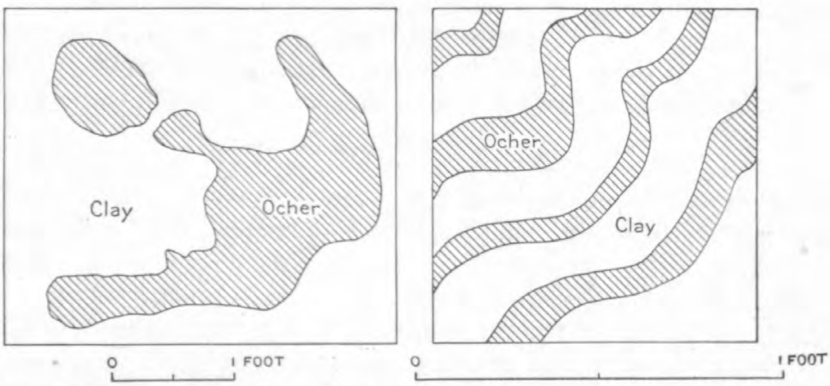

FIGURE 35.—Sections illustrating the stratified and unstratified occurrence of ocher at mine of Keystone Ocher Company, Fleetwood, Pa.

WILLIAMS PLANT AT FLEETWOOD.

The C. K. Williams plant adjoins that of the Keystone Ocher Company just described and differs very little from it.

It has been run for four years under the present management, but for the past twenty-seven years it has been worked intermittently, chiefly for the iron ore, which is found in the upper levels and which is now practically exhausted. Old drifts and shafts show that considerable work was formerly done on the property in working out the limonite deposits.

The present hoisting shaft extends vertically downward 91 feet to the bottom of the lower level and 126 feet to the bottom of the sump, which receives all the mine water and is pumped out at intervals.

Fifty feet from the main hoisting shaft there is an air shaft 46 feet deep, connecting with the upper level of the mine. The underground workings are similar to those of the Keystone Company, but are larger. The two levels are connected by chutes and by an old shaft which has been retimbered and repaired for the passage of the miners.

The washing and drying plant consists of a log washer, 26 floating troughs 16 feet long, four mud dams, and four drying sheds.

The ocher and iron ore occur in pockets, the ore predominating in the upper levels and the ocher in the lower, with clay between. The deposit seems to be in the form of a horseshoe extending along the hill, with its greatest dimension parallel to the hill. The bands of iron ore, clay, and ocher appear to run horizontally. The underlying rock is quartzite, which outcrops along the ridge with a dip of 75° toward the bottom of the hill.

The ocher found at this mine is of three grades, as follows:

1. "Gold dust," called No. 1, the purest variety.
2. "Gravel ocher," which is good ocher but contains particles of limonite that have to be washed out.
3. Clay and ocher, which is the poorest variety and contains pieces of chert up to 2 feet in diameter. The clay is red, yellow, white, and purplish and is of no value.

The time taken to treat the ocher varies, but in general it takes a month to completely fill the mud dams and three weeks more for the material to dry sufficiently to permit being shoveled. When it has dried to the consistency of a stiff mush it is put in the drying sheds, where it has to be left one month more before it is in condition to grind. The material is finished at the company's mills at Easton, Pa.

ERWIN PLANT AT TOPTON.

Henry Erwin & Sons' plant at Topton is one of the larger plants of the district and is worked entirely by open cut. When visited the workings were filled with water, but from an examination of the surrounding country the occurrence appears to be identical with that of the other plants located along the base of the same chain of hills. The ocher is of high grade and is associated with limonite and the other common impurities. It is treated in a log washer and settling and floating devices similar to those at Fleetwood, six mud dams being used to handle the output from the floating troughs. It has been worked intermittently for thirty years, and its output at present goes to the company's plant at Bethlehem, where it receives final treatment.

A smaller plant located near that just described and provided only with facilities for hoisting the ocher was owned by the Atlas Company, but the company has dissolved and the plant has been abandoned. There is one main hoisting shaft and a number of test pits, but no evidences of extensive workings.

LONG PROPERTY AT HANCOCK.

Dr. W. P. Long's property is a quarter of a mile south of Hancock. It shows signs of long abandonment, as no shafts or workings remain open. A considerable quantity of ocher is stocked in piles, and it seems to be of good color and weight. The surrounding ground is honeycombed with test pits, in which water has risen very high. It has been found impossible to construct shafts that will last beyond one working season, as the wet clay breaks the timbering of shafts and gangways, and it was partly because of this trouble that the place was abandoned. The veins on the property dip southeast. They were worked to a depth of about 80 feet below the surface, but at greater depths they were valueless. There are now no remains of hoisting machinery, and washing apparatus was never installed.

PRINCE PLANT AT ALBURTIS.

The Prince Metallic Paint Company has a plant in the town of Alburtis for roasting and grinding the ocher obtained from its mines, which are 1½ miles northwest of the station. The ocher, just as it comes from the mine, is charged into a rotary kiln 30 feet long and 2½ feet in diameter, rotating at a speed of one revolution in 55 seconds. The ocher is charged in at the upper end by shoveling. The kiln is fired at the lower end with soft coal and is blown by a Champion blower No. 4. It is revolved by means of a chain driven by a sprocket in the center of the kiln. After coming from the kiln the ocher is crushed and ground in three buhrstone grinders of Sprout-Waldron make, each machine grinding 18 barrels a day. It is packed into barrels by a device known as a "packer." The packer consists essentially of a platform raised and lowered by a cam, so that the barrel resting on the platform has its contents shaken down most completely.

At the mine from which the mill just described draws its material all the workings had caved in during the winter's idleness, and as they were close to the surface the timbering in the stopes and drifts was exposed to view. The caved-in workings extend over a distance of about a third of a mile. Where visible the ocher lies from 4 to 6 feet below the surface and contains many nodules of limonite and fragments of a thinly bedded sandstone. The overlying soil contains fragments of shale. The timbering is of round 6-inch timbers spaced 5 feet apart, with sawed slabs used as lagging.

The remains of the hoisting machinery were intact and consisted of a two-man windlass arranged for hoisting in balance buckets of 1½ cubic feet capacity.

BEAR PLANT AT BREINIGSVILLE.

The Bear Brothers' workings lie 1½ miles northwest of Breinigsville and include both open-pit and underground workings. When visited the plant was not in operation but showed signs of having been worked within a year, as the equipment was in good repair and a large quantity of ocher was on hand. The plant consisted of a boiler and engine room, with hoisting machinery for hoisting the ocher up the shaft and pulling the loaded cars up an incline from the shaft and pit workings to the log washer. The ocher is treated by the usual floating processes and is dried and ground on the premises. A rotary kiln of antiquated design was used to burn the ocher when the demand called for it. The shaft had two compartments and was provided with a Cornish pump to drain both the open-cut and the underground workings. At the time of visit the water was very high in all the workings and the deposit could not be seen. The deposit occurs near the contact between the Shenandoah limestone and the overlying Ordovician slate, and fragments of slate are common in the excavated material. The water appears very sulphurous, probably owing to pyrite. It is said that stringers of metallic copper have also been found in the material.

DEPOSIT AT CAMELS HUMP.

The deposit at Camels Hump is at present operated by C. K. Williams, of Easton. It is an umber deposit and lies 6 to 10 feet below the surface of the ground where it is worked. From the surface downward the section is as follows:

Section of umber deposit at Camels Hump, Pa.

	Ft.	In.
Dark soil	3	
Reddish-brown material		18
Light-yellow residual material	4–5	
Yellow residual material		3–6
Dark-brown umber (base not exposed)	6	

Fragments of weathered quartzite are abundant in the deposit and it is probably a result of decomposition of the quartzite. The brown color of the umber is due to the presence of manganese. This property was formerly worked by the Erwin Company, but very little material has been taken out. It is worked as an open cut and the umber is loaded directly into wagons. It has to be ground and floated, and when finished it brings from $18 to $20 a ton.

ERWIN PLANT AT BETHLEHEM.

Henry Erwin & Sons have a mill at Bethlehem for the final treatment and packing of the paint ores. It is situated along Monocacy Creek, on the Lehigh and New England Railroad, three-quarters of a mile north of Bethlehem. Here are received paint ores from all parts of the world, which are ground, roasted, and mixed for shipment. The mill draws its principal ocher supply from the firm's mine at Topton, previously described, and manufactures it for use principally as an oilcloth base. Water power is used and the grinding is done in French buhr and emery mills. Most of the umber is obtained from Turkey and Sicily, the sienna from Italy, and the ocher from the United States. The American sienna brings $20 a ton and the imported sells for $100 to $150 a ton.

Much red-oxide paint is also made at this mill from copperas (iron sulphate, $FeSO_4$) and oyster-shell lime. The copperas is obtained from a wire factory in New York. Calcite obtained from Franklin Furnace, N. J., is added to the mixture to dilute its strength. Clinton iron ores are also ground and used as mortar colors.

MOOSEHEAD DISTRICT.

GEOLOGY.

ROCK FORMATIONS.

The rocks in the vicinity of Moosehead belong to the Mississippian series of the Carboniferous system. The extreme eastern part of Luzerne County is composed of the Pocono sandstone, and to the west and south this is overlain by the red Mauch Chunk shale.

The Pocono is composed of gray sandstones with shale and fine siliceous conglomerate and varies in thickness from 800 to 1,300 feet or more. The Mauch Chunk shale consists of reddish, greenish, and yellow shale, with gray and greenish-gray sandstone, in some parts containing quartz and red shale pebbles, and gray conglomerate, some of which also contains red shale pebbles.

At the abandoned Moosehead station on the Lehigh Valley Railroad there is an exposure of 124 feet, as follows:

Section of rocks exposed at Moosehead, Pa.

	Feet.
Conglomerate, gray, siliceous	20
Sandstone, gray	4
Conglomerate, gray	6
Sandstone, gray	3
Conglomerate, gray	3
Sandstone, gray	7
Sandstone, gray, with quartz and red shale pebbles	15
Conglomerate, slate pebbles, large red shale fragments	5
Sandstone, hard, gray	5
Shale, red	28
Shales, yellowish green	10
Ocher, white and yellow	18

The rocks have a low dip (2° to 5°) to the north. The ocher mine is on a low anticline. Considering the structure as exhibited at the ocher mine, at the tunnel of the Central Railroad of New Jersey, and east of the railroad at Wrights Creek, the above-noted series of sandstone and shale beds exists as a flat synclinal to the north of Tunnel Ridge and overlies the southward-dipping Pocono rocks which constitute the south slope of Nescopec Mountain. This series of rocks should hence be placed at the base of the Mauch Chunk, as they are evidently the lowest rocks of that formation.

ORE DEPOSITS.

The ocher deposit at Moosehead is a true bedded deposit. At the mine the bed has a thickness of 15 feet, the ocher being overlain by 12 feet of red shale. The ocher is a soft, crumbling rock, chiefly of a buff-yellow color, with small local bands of a variegated dark color.

The Luzerne Ocher Company owns a tract of about 3,000 acres near Moosehead, and the bed of ocher is practically continuous over this area. As before noted, the ocher bed is on a low, flat anticline and is underlain directly by the Pocono sandstone, which is very hard and compact at this place. Owing to the soft, crumbling nature of the ocher, it is very easily mined and treated. The ocher is really a bed of soft shale containing more than the usual amount of iron oxide. This percentage is low, however, compared to the iron content of a high-grade ocher.

LUZERNE PLANT AT MOOSEHEAD.

The Luzerne Ocher Company's plant, the only one in the district, is 1½ miles from Moosehead, Pa., or 5 miles north of White Haven, Pa. It has been in operation by the same company for twenty-five years. A spur runs from the Lehigh Valley Railroad to the plant. The mining is done entirely by open cut, 12 feet of shale overlying the ocher bed. There is practically no timber on the mountain side, and in winter snow makes mining impossible, so that practically no work is done from December to March.

The mining is done by blasting away the cover and then blocking out the ocher and breaking it up—first with a charge of dynamite to enlarge the drilled holes, and then with a charge of black powder to bring it down. It is then broken into small pieces and trammed to the mill. At the mill it is crushed and ground and finally bolted through silk screens of 156 mesh. There are 12 of these screens, arranged parallel to one another and placed on a slight incline, so as to cause the ground material to pass along. It is fed in at the higher end and the pieces which are too large pass through to the lower end, where they are discharged and reground. The capacity of this set of screens is 20 tons per day. The ocher is light yellow and is used as an oilcloth base.

The quantity of material in this deposit is practically unlimited, as the company owns 3,000 acres of land underlain by it. The total production to December 31, 1908, is reported to have been approximately 50,000 short tons of ocher, and the average retail value of the finished product is about $8 a ton.

ANALYSES.

The following analyses, secured from Henry Erwin & Sons, represent the composition of typical finished ochers. The first three are probably mixtures containing foreign ochers, but the fourth (Topton) is a local product:

Analyses of ochers.

	SiO_2	Fe_2O_3	Al_2O_3	CaO	$CaSO_4$	MgO	MnO	S	P_2O_5	H_2O
Easton ocher	39.70	37.64	13.26			1.37				7.83
"Pure Prince's Brown"	32.8	46.89	10.76	3.00		1.52	1.39	0.5 to 2.0	Tr.	
"Light red oxide"	2.05	37.29			57.65					.10
Topton ocher	55.50	17.49	18.66							[a] 8.35

[a] Combined.

Analyses of ground slate and sienna.

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	MnO	H_2O
Ground slate [a]	58.84	6.50	19.04	1.60	1.50	2.47	1.75		
Italian sienna	19.23	74.24	1.32	0.48	Tr.			0.50	[b] 4.23

[a] Loss on ignition, 7.24. [b] Combined.

The following analyses for ferric oxide were made in the laboratory of the department of geology at Lehigh University by the writers:

Percentage of ferric oxide (Fe_2O_3) in ochers.

Finished ocher (Bear Bros., Breinigsville, Pa.)	19.50
Finished burnt ocher (Prince Metallic Paint Co., Alburtis, Pa.)	47.32
Finished ocher No. 2 (Henry Erwin & Sons, Topton Pa.)	11.85
Finished ocher No. 4 (Henry Erwin & Sons, Topton, Pa.)	18.42
Finished ocher (Keystone Ocher Co., Fleetwood, Pa.)	27.77
Finished ocher (Luzerne Ocher Mfg. Co., Moosehead, Pa.)	6.26

SUMMARY.

The ocher deposits of eastern Pennsylvania occur in two districts, the Reading-Allentown district and the Moosehead district.

The Reading-Allentown ocher occurs in the Shenandoah limestone, of Cambro-Ordovician age. It is a residual deposit and was formed from the iron in the limestone during its disintegration.

The Moosehead ocher occurs as an original bedded deposit in the Mauch Chunk shale. It is of low quality with respect to its iron content.

Mining is carried on by open cut and also by drifting and stoping. The ocher is washed, dried, and ground.

The ocher market fluctuates greatly, and most of the mines are worked only when there is a demand for the product.

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PAINT-ORE DEPOSITS NEAR LEHIGH GAP, PENNSYLVANIA.

By FRED T. AGTHE and JOHN L. DYNAN.

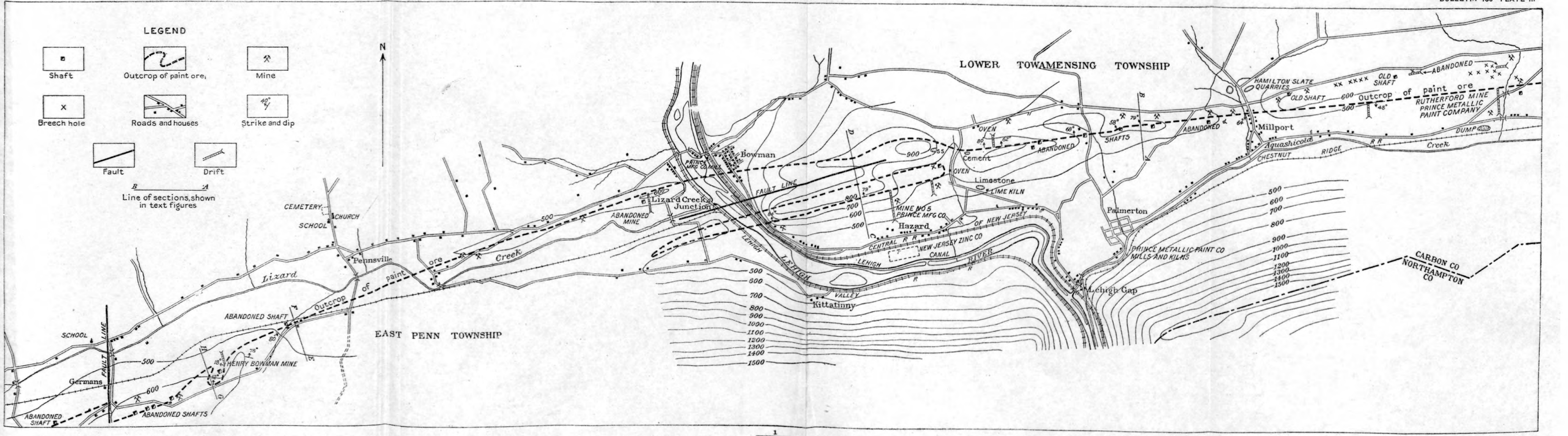
LOCATION.

The paint-ore deposits here considered are situated in the southern part of Carbon County, Pa., 7 miles below Mauch Chunk, and extend in a general east and west direction for about 20 miles. The "paint beds" are of sedimentary origin, Devonian in age, and lie between the Oriskany sandstone and the Marcellus shale. They have been traced west to Germans, 5 miles west of Lehigh River, and east as far as Little Gap. The area in which the deposit lies is a narrow strip, with the stated east and west limits and from one-half mile to 2 miles wide, comprising, in addition to the "paint beds," outcrops of Helderberg limestone, Oriskany sandstone, Marcellus shale, and Hamilton shale.

HISTORY.

It is generally conceded that Mr. Robert Prince and Mr. Rutherford were the first to find the ore and recognize the adaptability of the material for the manufacture of metallic paint. The ore was first found along the outcrop between Bowman and Millport in 1856. These gentlemen independently recognized the quality of the ore as being somewhat different from that of ordinary limestone, and had the material analyzed. Analyses convinced them that the ore was applicable to the manufacture of metallic paints. Both opened deposits. Mr. Prince utilized a mill on Big Creek which he owned to grind the ore and shipped it to Weissport, on Lehigh River, for the market.

Competitors soon appeared in the field, and so great was the desire to find a portion of the bed which could be worked advantageously that the entire outcrop has been prospected from Germans on the west to Little Gap on the east. Indeed, the bed has been traced as far as Schuylkill County along the Lizard Creek valley, though no ore of any value has been removed west of Germans.



MAP SHOWING OUTCROP OF PAINT-ORE BED NEAR LEHIGH GAP, PA.

The two companies now operating are the Prince Metallic Paint Company and the Prince Manufacturing Company. The former company, which developed from the early Rutherford operations, has mines along the ridge east of Lehigh River.

At present the Prince Metallic Paint Company has options on many properties where ore is supposed to exist, and practically all the property along the ore-bed outcrop from Palmerton to Little Gap is controlled by it.

The Prince Manufacturing Company has mills at Bowman, most of the ore being hauled from Hazard, a distance of about 2 miles. This company is the outcome of Robert Prince's discovery and was organized in 1876. The mines of this company are located at Hazard.

Besides these operating companies, the William G. Freman Company, of Mauch Chunk, Pa., has run a drift into the bed along the strike at Little Gap. The tunnel is well timbered and modern in its construction, though little ore has been removed from it. The development of this mine depends upon the availability of the ore, as no expense has been spared to make the operations thorough and modern.

GEOGRAPHY.

This region is part of the Appalachian province and is made up of a series of hills and valleys running east and west. Most prominent of these on the extreme south is Blue Mountain, formed by resistant Silurian and Ordovician formations. This stands as a high, steep, knifelike ridge, 1,100 feet above Lehigh River, which cuts through the ridge at Lehigh Gap.

The Oriskany sandstone forms the most peculiar topographic feature of the region. (See Pl. III.) With only a few interruptions, it stands out as a long continuous ridge. West of the Lehigh this ridge is very narrow and precipitous, at places forming a vertical cliff. In several places it presents the appearance of a huge artificial wall. The slopes are covered with large, detached angular blocks. The dip here is nearly vertical, and immense blocks, their greater dimension parallel to the bedding, stand out on top of the ridge.

The Oriskany ridge is double for a short distance on each side of the Lehigh, owing to a fault that runs along parallel to the strike of the formation and dwindles out gradually in each direction.

East of the Lehigh the ridge is more rounded, except for a short distance from the river eastward a mile beyond Bowman. It loses its double character halfway between Hazard and Lehigh Gap, and from there runs eastward, gradually increasing in width and height as the dip flattens, until at places it rivals Blue Mountain.

Above the Oriskany occur softer rocks, the "paint beds," Marcellus shale, etc. They are marked by a series of gently rolling hills and valleys.

All the formations except the Oriskany weather so readily that outcrops are very hard to find. Moreover, the débris from the Oriskany fills most of the valleys, covering up any outcrops that might occur.

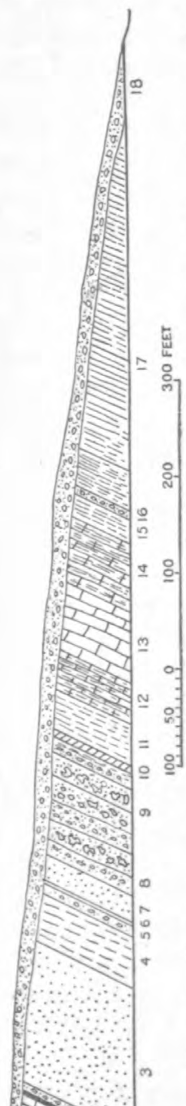


FIGURE 36.—Section through Kline tunnel, Hazard, Pa. 0–2, "Paint beds" (0, cement rock; 1, paint ore; 2, clay); 3, Oriskany sandstone; 4–14, Helderberg limestone (4, shales; 5, yellow clay; 6, hematite; 7, sandstone; 8, clay and flint; 9, arenaceous clay; 10, flint; 11, shale; 12, limy shale; 13, limestone; 14, limy shale); 15, shale; 16, clay; 17, shales; 18, river wash.

GEOLOGY.

GENERAL STATEMENT.

The rocks immediately associated with the paint-ore deposits are sandstone, clay, shale, and limestone, of Devonian age.

These strata outcrop in narrow bands running east and west. At most places the structure is that of a number of monoclinal, conformable sedimentary beds. At the outcrop the beds usually show overturned steep dips to the south. Below the surface there is probably another flexure restoring the normal dip. The country thus consists of the truncated ends of a slightly overturned anticline, which has been entirely eroded south of the present exposures.

The structure is complicated between Bowman and Hazard by the presence of a syncline of Oriskany south of the main outcrop. This is discussed more in detail below.

Large portions of the country are covered with glacial material brought down by the rivers. This shows most prominently on the hillside between Bowman and Hazard, where there are glacial clays and bowlders of material which has evidently been carried from the north.

STRUCTURE.

The structure of this whole region may be explained by a discussion of the Oriskany sandstone, as all the other strata are conformable with it and, owing to its resistant qualities, it is the most prominent. (See figs. 36 to 40.) The Oriskany is also the only bed with good exposures and is quarried in many places for sand. Beginning at the east the main outcrop is a long straight line, broken where the Lehigh cuts through the ridge at Bowman and in places by smaller streams. This continues west of the river as far as the outcrop was followed, with a few irregularities in the vicinity of Germans.

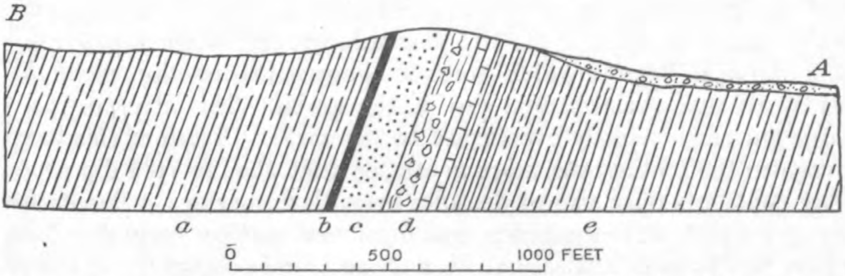


FIGURE 37.—Section along line *A-B*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

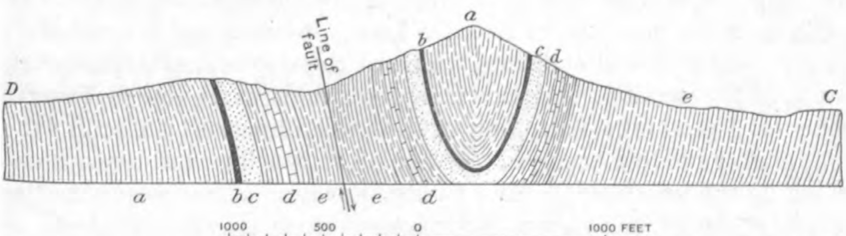


FIGURE 38.—Section along line *C-D*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales. Vertical scale exaggerated.

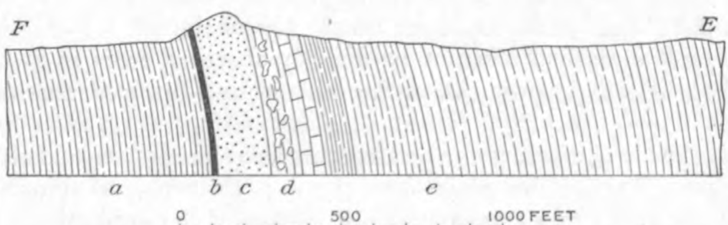


FIGURE 39.—Section along line *E-F*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

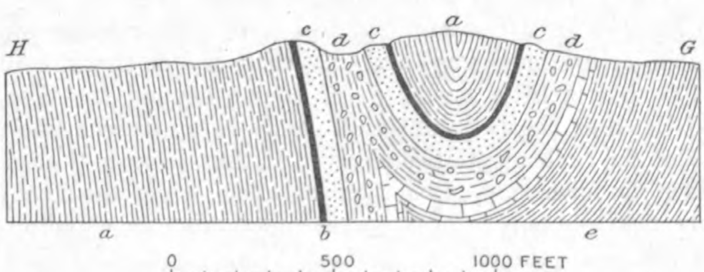


FIGURE 40.—Section along line *G-H*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

The dip along this outcrop is in general about 70° S., but at places it is nearly vertical. The dip becomes greater with depth until it is vertical, beyond which point it changes in direction until the strata resume their normal dip to the north. This structure is a large anticline, slightly overturned to the north. North of this large overturn the folding was more gentle, so that the inverted dip probably continues only a short distance beneath the surface. The entire southern part of the anticline has been removed by erosion. Most of the northern arm, also, has been eroded, just enough being left to still show the inverted dip.

In places the anticline has been faulted along its axis, and to this are due the double outcrops which occur around Bowman. The main anticline was not one simple fold but contained a number of minor anticlines and synclines. One of these synclines was formerly south of the locality where Bowman now stands, extending for several miles and gradually flattening out in each direction. A fault running east and west occurred north of this syncline, the downthrow being on the south side. This faulted-down syncline now forms the secondary ridge, or outcrop, of Oriskany, which stands out so prominently. This ridge extends a little east of Hazard and only a short distance west of Lehigh River. Both arms of the syncline dip steeply; the Oriskany has almost, in fact, been folded back on itself. In some places the Hamilton is not found on the top of the hill.

The fault described can not be directly observed from exposures; therefore little is known concerning its nature, dip, and amount of throw.

The other irregularities in the structure are those in the vicinity of Germans. West of this place the outcrop is thrown several hundred feet to the north by a transverse fault. East of the same town there is another irregularity. The outcrop here curves abruptly and retreats to the south, the dip flattening considerably. This produces a small valley, filled by the Hamilton shale. The outcrop turns again eastward for a few hundred feet, and thence makes another sharp double turn northward and then eastward, so that it continues parallel to but a little north of the course beyond the first turn. Toward the east the bed continues nearly in a straight line to the vicinity of the fault mentioned above. It thus appears that at some time after the formation of the main anticline, while the strata were nearly vertical, pressure in an east-west direction caused a folding of the beds at this point, the axes of the folds being vertical. This folding was very close, so that instead of the three ridges of Oriskany which would naturally be expected there is in fact only one. The southernmost outcrop has been worn down, while the other two are folded to form only one ridge. A section through this locality shows the full thickness of the Oriskany three times, two of these thicknesses, where the folding is closest, being directly superimposed.

ROCK FORMATIONS.

HELDERBERG LIMESTONE.

The Helderberg limestone here appears in the form of 150 to 215 feet of beds of clay and flint. The section in the Kline tunnel (mine No. 5) at Hazard is as follows (see fig. 36):

Section in tunnel of mine No. 5, Hazard, Pa.

	Feet.		Feet.
Flint	45	Clay and flint	72
Red clay	1	Fine sandstone	2
Black clay	9	Clay and flint	30
Hematite	1	Sandstone	4
Clay, with chert	3	Flint	20
Sandstone	24		211

The flint beds are regularly stratified. They are of massive structure, with well-developed joints. In color the flint varies from white to black, brown being the most common.

The clay beds consist of a soft and unctuous clay, either red, yellow-white, or blue.

The sandstone beds resemble those of the Oriskany, and vary from coarse to very fine grained. The hematite bed is a low-grade red hematite of no economic importance.

ORISKANY SANDSTONE.

The Oriskany sandstone is about 150 feet thick and consists of a hard sandstone. In composition it is almost a pure quartz sand, running frequently as high as 98 per cent silica. The material varies from very fine grains to coarse pebbles up to a quarter of an inch in diameter. The cement is usually calcareous, and when exposed to the weather dissolves out rather easily. Where this occurs the sandstone crumbles. It is due to this ease of disintegration that the rock is quarried so extensively for sand. The grains are white to yellowish brown in color, and are usually well rounded.

The Oriskany is penetrated by numerous joints, in some places three different systems occurring. There is great difficulty, where the joints appear, in distinguishing them from the bedding planes. The most important system of joints, which extends practically throughout the length of the Oriskany in this region, has a dip of 40° to 50° S. As a result, the south slopes of the Oriskany hills contain many more bowlders than the others, because the large blocks produced by weathering fall to the south.

The Oriskany is at present being worked in a number of places for sand. There are three operating quarries at Fenstermacher's, one opposite Bowman, and numerous smaller ones on the east side of the river. The sandstone after blasting down is easily crushed, and the material is sold for use as molding sand, for concrete, fire brick, etc.

The characteristic fossil of the Oriskany in this region is *Spirifer arenosus*, the specimens of which are large and well preserved.

"PAINT BEDS."

The "paint beds" consist of the following members: Cement rock, 25 feet (variable); paint ore, about 2 feet; and clay, 8 feet—a total of 35 feet. The correlation of these beds with the New York formations has not been satisfactorily determined. The lower 20 feet of the cement bed consists of hard, compact blue rock much resembling the paint ore. It is very fine grained and contains small veins of quartz and calcite. There is no trace of the slaty cleavage so prevalent in the cement rock of the Lehigh district. The upper 5 feet of the cement rock consists of a cherty limestone, the chert occurring as black nodules.

The cement rock was formerly burned for cement in a number of places. It is said to have produced a very good cement, and the material was used in building the locks of the Lehigh Canal, also for several reservoirs in the vicinity.

The paint ore is described in detail below.

The clay beneath the paint varies greatly in its characteristics. It has been provisionally correlated by the New Jersey Geological Survey with the Esopus ("Caudagalli") grit of New York. Fragments have been found showing the typical cockscomb markings, but nowhere in place. This material is a hard white sandy shale. Its color is blue, white, yellow, and red. Its thickness is from 2 to 9 feet.

MARCELLUS SHALE.

The Marcellus consists of slate or shale. It is usually a compact, fine-grained, blue to black shale. The cleavage is very well developed and is in general parallel to the bedding but is not so everywhere. Locally the shale has been greatly crushed and contorted, so as to result at many places in the formation of a series of grooves parallel to the cleavage. This produces a very striking resemblance to petrified wood. The Marcellus weathers easily, breaking up into small pieces and losing its dark color. Hence there are few good outcrops and it is difficult to obtain specimens except from the underground workings. The thickness of the formation is about 800 feet.

The Marcellus was formerly quarried in a few places for roofing slate. These operations have been abandoned, with few exceptions, owing to the greater strength and other advantages of the Martinsburg shale ("Hudson River slates") to the south. There is one large quarry still working at Millport, Pa.

ORE DEPOSITS.

DESCRIPTION.

The paint ore in this vicinity consists principally of carbonate of iron. This material is found in the beds between the Marcellus shale above and the Oriskany sandstone beneath. The ore bed varies in thickness, in some places being 1½ to 2 feet thick and in others pinching out to but a few inches.

No outcrops were observed anywhere along the entire portion of the bed traversed. Even though the bed is approximately vertical in many places, the débris from the Oriskany, which projects prominently above the other formations, has entirely covered the outcrop. The presence of test pits and air shafts and the outcrop of the Oriskany mark the general position of the bed.

There is no sharp line between the ore and the Marcellus shale above. Descending waters have carried the mineral materials into the lower clay, so that the overlying cement rock is usually low in mineral value and shows up poorly after burning. The miners distinguish the iron-bearing strata chiefly by the specific gravity of the material. The lithologic characteristics of the paint ore and cement rock are very similar. They both resemble a compact limestone, rather dark blue and crystalline. Upon close examination, however, the rather compact structure of the paint ore and the presence of pyrites in most places are noticeable; also the fact that the ore is not so crystalline as the cement rock.

The ore throughout resembles a blue limestone, and were it not for the high specific gravity the casual observer would not suspect the presence of any mineral of value. It is dark blue and is usually associated with pyrites. The ore mined from the first tunnel, known as the Kline tunnel (mine No. 5) is pyritic, but farther east the ore has not this pyritic character and also bears fewer fossils. In the extreme east of the region traversed the ore is pyritic in places, as, for instance, the ore in the mine east of Millport; but in the vicinity of Little Gap the ore is not pyritic. In the mine east of Millport, however, the drift was run in too high, so that the paint bed has not been much exposed by the workings. As very little ore has been removed up to the present time, its exact characteristics are somewhat doubtful. It is safe to assume, however, that the ore closely resembles that taken from the Rutherford tunnel, located west of this mine, near Millport, Pa.

The ore bed is a compact mass, is almost entirely mineralized, and contains few waste materials. For this reason the only separation that is necessary is the hand sorting, which is carried on in the mine. Successful mining of the ore requires only that care be exercised in stoping. The clay below is easily removed, being soft and unctuous. The cement rock above is rather more difficult to separate, but with some experience the miners become very adept in judging the ore. The ore is so easily separated underground that the ore pile is nearly all pure paint rock. This rock is generally placed under sheds, so that the weather will not affect it. It is common to see lying around shafts, drifts, etc., fragments of this ore which are reddish in color throughout, having been oxidized to the ferric state since the ore was mined. This is called "sun-burned ore."

THEORIES OF ORIGIN.

The presence of carbonate of iron, associated as it is with rather compact cement rock above and a clay beneath, has given rise to several theories as to the origin of the ore.

One theory suggests that the "paint beds" were deposited and concentrated in a swampy region during Devonian time. From a careful study of the beds in proximity to the ore it has been observed that they seem to be richest where the underlying Oriskany sandstone contains very little iron. The Oriskany is now extensively worked at these places for white sand. This theory suggests that the Oriskany was deposited under peculiar climatic conditions. The climate was probably very dry, and for this reason little iron was leached out of the various formations and deposited in the sea while the Oriskany sandstone was being deposited. Later there was a long interval during which the climate changed and became rather moist, so that the iron was leached from the exposed formations and deposited in the swamp. It is rather difficult to explain, however, the origin of a band of hematite iron ore found beneath the clay bottom of the paint bed. It is plausible, however, to assume that this bed, being composed of oxidized material, was first deposited during the change from a dry to a moist climate.

The last period of deposition and concentration was marked by the formation of iron carbonates. The overlying Marcellus shale is rather carbonaceous, especially the lower measures. This carbonaceous deposition is exemplified in the region to the east, where the Marcellus shale has been worked for "coal," as at Kimbletown, about 11 miles east of Lehigh Gap. The abundance of carbon in the Marcellus would seem to have some connection with the iron carbonates of the "paint beds." It may be safe to assume that the necessary carbon for the ferrous iron carbonate was obtained from these measures, reducing the iron from the ferric to the ferrous state and forming a carbonate iron ore. The pyrites found disseminated throughout the "paint beds" have been formed also by the reducing action of the carbon, probably changing the iron from a sulphate to a sulphide.

Another theory which may be advanced is that of metasomatic replacement of the cement rock by iron. The descending waters bearing iron in solution may have replaced the cement rock, molecule for molecule. The one objection to this theory is that the iron in the paint ore is in a ferrous condition, and that as descending waters usually contain oxygen the iron would presumably be in a ferric state. The iron, however, might have been reduced by the carbon leached from the overlying formations at some period after its precipitation.

It has been found that the ore changes to limonite near the surface, owing to oxidation, also that the ore grows leaner as the distance below the water level is increased. Such conditions as these support the theory that the ore deposit is due to descending waters. No extensive observations have been made at great depths below the ground-water level. It has been found where a few test pits have been sunk from the drifts that the ore grows leaner with depth and presents a rather shaly appearance. However, too few observations have been made for this condition to be stated as absolutely prevailing, for some of the miners in the vicinity maintain that the ore is concentrated in the lower workings and that ore will be found of a much better grade when it becomes necessary to work the lower levels.

Eastward from Little Gap the Oriskany becomes very thick and forms a well-rounded mountain closely resembling the Blue Ridge and almost as high. It has been found by the operations carried on in the vicinity that the ore is entirely a low-grade hematite. Though a tunnel has been driven through the base of the mountain, no carbonate ore was found. Just why the ore is of different character in this locality is a matter for conjecture, but the change may have been caused by the oxygen-bearing percolating waters.

ANALYSES.

Partial analyses of the ore are as follows:

Average partial analysis of crude paint ore of Lehigh Gap district.[a]

Metallic iron	33
Metallic manganese	.01
Silica	25
Carbon dioxide	25

[a] Averaged from analyses in report of Second Pennsylvania Geol. Survey, 1886; also analyses furnished by Prince Metallic Paint Co., Allentown, Pa.

The specific gravity of the paint ore varies from about 3.2 to nearly 4.0. It contains, in addition to the substances stated above, small amounts of lime, magnesia, sulphur, and phosphorus.

MINING.

PRESENT EXTENT OF WORK.

The paint ore has been very extensively worked in the past along the entire length of outcrop described above. Most of the old workings have been abandoned, and there are at present no working mines west of Lehigh River. Within a mile of Germans are five old shaft mines and two that were worked through tunnels. There are also a number of abandoned mines east of the river.

The mines now working are the two tunnels and the shaft of the Prince Manufacturing Company at Hazard and the tunnel and shaft of the Prince Metallic Paint Company east of Millport.

METHODS.

The deposits are worked through both tunnels and shafts. Tunnels are used wherever practicable. In most places the Oriskany sandstone, next to which the ore occurs, stands out as a prominent hill, and the favorite method of working the bed has been to drive a tunnel from the hillside through the Oriskany, striking the ore at a depth of 50 to 150 feet below the top of the hill. This gives the tunnel a length of 500 to 1,500 feet. In many places, particularly in the older workings, it appears that a great part of this length could be more economically carried on as an open cut, as the overburden is locally but a few feet thick.

The Kline tunnel of the Prince Manufacturing Company at Hazard may be taken as a typical example of the tunnels of this region. This tunnel starts in the river wash, which here covers the side of the hill, and extends 1,400 feet in a north-south direction to the ore bed. From the end of the tunnel drifts are driven along the strike of the bed, which is east and west, and the ore is stoped out by the overhead method, with filling. Where the tunnel goes through a great thickness of soft shale and clay, close timbering and lagging is necessary. The tunnel is 6 feet high and about as wide. The sets consist of two posts and a cap of 8-inch timber and are placed 3 to 6 feet apart. They are lagged with rough poles 15 feet long. The track has a gage of 2½ feet. No timbering is necessary in passing through the Helderberg limestone or the Oriskany sandstone.

The mines east of Millport probably show to best advantage the mining methods in use, and a detailed description of one of these mines follows.

The ore bed here outcrops well back in the Oriskany hill and dips steeply from 60° to 70° due north. It has been worked for 2,000 feet along the strike, and a timbered air hole marks the present western limit of the workings. One thousand feet east of this the bed was first encountered by a tunnel driven from the hillside 999 feet due north. Six hundred feet east of the point where the tunnel strikes the bed is the bottom of the shaft, and from this point the workings continue 400 feet farther east. This tunnel is similar to the one described above. A shaft was put down in the hanging wall and struck the bed at a depth of 159 feet, the same level as that at which the tunnel enters it. The shaft is 5 feet square and is timbered with 6-inch cribbing, on the inside of which are nailed 1-inch boards forming a complete lining.

The drifts along the strike are 7 feet high, 5½ feet wide at the bottom and 5 feet at the top. They are driven along the ore, which is here 2 feet thick, and are timbered their entire length. Only one post is used in the sets, as the cement-rock hanging wall is sufficiently firm to permit supporting one end of the cap in a hitch cut in it. Nine-inch timber is used. The sets are placed 3 feet apart and are closely lagged.

A pillar is left to protect the shaft, and beyond this the stoping commences. The drift is driven 30 to 40 feet at a time, after which a section of this length is stoped up to the surface, or to the overburden of earth and clay. Overhead stoping with filling is the method used. The stope is kept inclined in advancing, so that the top corner farthest from the shaft is kept about 20 feet ahead of the face of the drift. The ore can thus be rolled down from the working face to the drift. Six-inch props are placed at intervals to support the roof while the ore is being removed. The stopes are 4 to 6 feet wide, 2 feet being ore and the rest clay and cement rock. The ore is carefully sorted out and rolled down. The clay and cement rock are used as filling. At intervals air holes are driven from the top of the stopes to the surface. The air is then carried from them to the working places by a small monkey gangway, which runs along the top of the worked-out and filled-in stopes. This also is timbered and lagged. As the workings advance, new air holes are driven and the old ones are abandoned.

The ore is blasted down with dynamite, the holes being drilled by hand. After being sorted and rolled down to the drift it is loaded into boxes holding about half a ton. These are mounted on trucks and trammed to the shaft. The boxes have rings at the corners, and four chains suspended from the hoisting rope are hooked in these rings. The hoisting is done by a horse hoist. The ore, after hoisting, is stored in sheds ready for the mill.

This mine is rather wet, but the natural drainage through the tunnel disposes of all the water. At present one shift of four men is engaged in stoping and the output is 10 tons a day.

OUTLOOK FOR THE INDUSTRY.

The mining problems so far have been very simple, because only slight depths have been attained, and natural drainage is in most places relied on to drain the workings. None of the mines has as yet opened a second level, because of the great horizontal extent of the ore. At the mine just described there is enough ore on the one level within the property lines to maintain the present output for over twenty-five years. It appears probable, however, that with the growing demand for metallic paints increased production will necessitate the opening of lower levels. The future of the region hence depends largely on the depth of the ore body, and practically nothing is known of this. The idea that the ore is due to deposition by descending waters does not argue well for its continuance with depth, but nothing can be definitely stated from our present knowledge. The deepest workings are in an old mine at Millport, where ore is reported to have been found at 200 feet.

The general conditions are very favorable to cheap mining. Shipping facilities are good, as the Central Railroad of New Jersey runs through Hazard and the Chestnut Ridge Railroad through Millport. The Lehigh Valley Railroad also furnishes ample means of shipment to the east and west. There are no expenses for fuel or mechanical power, and labor is extremely cheap.

PREPARATION OF PAINT.

METHOD OF TREATMENT.

The treatment of the ore, as carried on in this region, consists of calcining and grinding it to a fine powder, in which state it is sold to be mixed with oil.

The ore is carted from the mines to the mills, where it is dumped into bins. It is then broken up with sledges to about 6-inch pieces, when it is ready for calcination. This was formerly carried on in stone kilns, but these are giving way to more modern steel-jacketed shaft kilns. The kilns are generally situated at the foot of a hill, the ore bins being higher up, so the ore may be trammed over a trestle to the charging door at the top of the kiln.

Certain typical kilns are of brick construction, with sheet-steel sheathing 25 feet high and 10 feet in diameter. There are two fireplaces, one on each side, making the width of the kiln at the bottom 18 feet. Cordwood is used as fuel, and the average temperature attained is 500° F. The run lasts twenty-four hours, and every twelve hours 10 tons of calcined ore is withdrawn through the door at the bottom, a corresponding amount of raw ore being charged at the top.

The calcined material is very compact and of a dark reddish-brown color. It has the same composition as the finished product, the rest of the process consisting simply of grinding. The loss during calcination is about 20 to 25 per cent.

Two such kilns are in operation at Lehigh Gap. The product is trammed to the mill, 100 feet distant, and ground to buckwheat size by a gyratory crusher in the cellar. A conveyor then carries it to bins at the top, and thence it is fed automatically to the fine grinding apparatus on the first floor. This consists of three 36-inch horizontal buhr mills and three vertical mills. Their product is shipped in barrels containing 300 pounds.

Power for this mill is furnished by a 75-horsepower water turbine.

COMPOSITION AND PROPERTIES.

The ground paint ready for market has the following composition, according to the analyses of the Prince Metallic Paint Company:

Composition of ground paint from Lehigh district.

Fe_2O_3	41 –47	MnO	0.35–1.8
SiO_2	32 –37	P_2O_5	.14– .17
Al_2O_3	9 –11	S	.5 –1
CaO	.1–3	CO_2	1.5 –2.5
MgO	1.7– 3.5	H_2O	.6 – .9

The particular advantage of this paint is its great durability. Other advantages are that it requires no dryer and that it is free from grit.

The manufacturers, in their directions for using the paint, recommend mixing 7 pounds of paint with 1 gallon of boiled linseed oil. This is sufficient for one coat over an area of 500 square feet. Another important point claimed for it is that there is no trouble from the paint settling. The completeness of the grinding reduces the paint to an impalpable powder, which does not easily settle or harden.

USES IN THE ARTS.

The paint from this region is recommended by the manufacturer for both wood and steel, for use under the most severe conditions of exposure, as railroad cars, exposed structural steel work, etc.

There is more of this paint used for freight cars than for any other purposes. Other uses are for structural steel, filling in oilcloth and linoleum, tanks, ships, and in tin roofing.

The paint brings a price from $12 to $14 a ton.

PRODUCTION AND STATISTICS.

The entire production of the whole region to date is in the neighborhood of 100,000 tons. Of this amount 25,000 tons has come from the mines now operating at Millport. Approximately an equal amount has been mined from the present workings at Hazard, and the remainder was from mines now abandoned.

There is still available, above ground-water level, about 200,000 tons of ore, or enough to last for twenty-five years longer at the present rate of production. This estimate was made on the assumptions that the ore averages 1½ feet in thickness and that there is 65 feet above ground-water level.

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PHOSPHATES.

PRELIMINARY REPORT ON THE PHOSPHATE DEPOSITS IN SOUTHEASTERN IDAHO AND ADJACENT PARTS OF WYOMING AND UTAH.

By HOYT S. GALE and RALPH W. RICHARDS.

INTRODUCTION.

GENERAL OUTLINE OF INVESTIGATION.

On December 9, 1908, the Secretary of the Interior withdrew from all kinds of entry 4,541,300 acres of land in Idaho, Utah, and Wyoming, pending an examination of their phosphate resources. The lands withdrawn were not then supposed to be all phosphate bearing, but they included all areas in which, according to the meager evidence then available, valuable phosphate deposits seemed likely to be present. The field work done in the summer of 1909, on which this report is based, has led to the restoration of some of these lands and to the withdrawal of others, so that the total area now withheld from entry is 2,551,399 acres.

Two parties were detailed by the Geological Survey to examine the lands thus withdrawn. The larger party, which was outfitted at Montpelier, Idaho, about June 1, was in charge of Hoyt S. Gale and included R. W. Richards and C. L. Breger. W. H. Waggaman, of the Bureau of Soils, Department of Agriculture, who was associated with these geologists in the field throughout the season by agreement between the Bureau of Soils and the Geological Survey, assisted in the collection of representative samples of phosphate rock and made field chemical determinations of their content of phosphoric acid. George H. Girty, paleontologist, was with the party during June and July and, with the assistance of C. L. Breger, collected a large amount of material that is important in the study of the stratigraphic relations of the phosphate-bearing beds.

The other party, which was under the direction of Eliot Blackwelder, of the University of Wisconsin, examined phosphate lands in the extreme southern part of the area withdrawn and studied stratigraphic problems in the northern part of the Wasatch Mountains. The results of this work are presented on pages 536–551 of this bulletin.

Besides this geologic work, topographic work was done in two adjacent areas by parties of the Survey under the direction of A. E. Murlin and Albert Pike. One of these areas is in the extreme northeast corner of Utah and the other in the southeast corner of Idaho, and the two together include much of the more accessible parts of the phosphate fields.

During the season the larger geologic party examined about 1,200 square miles, mapped 400 square miles in considerable detail both geologically and topographically, and traced the outcrops of phosphate rocks in this area. Analyses of 330 representative specimens of phosphate rock show accurately the grade or quality of the material found.

The areal surveys made have defined the position and the geologic relations of the larger developed deposits, so that more reliable estimates of available tonnage can be made. The results of the careful study of the stratigraphic relations of the phosphate-bearing formations and the associated strata have simplified the work of identifying and tracing the deposits. Important outcrops of phosphatic beds have been found and mapped in areas lying beyond those now locally recognized as phosphate bearing, including deposits situated in readily accessible parts of the field and not yet covered by mining claims. Evidence has been obtained of the existence in this field of deposits of high-grade phosphate rock in strata of Jurassic age that are much younger geologically than the deposits hitherto recognized, and although the Jurassic deposits have not yet been shown to be of commercial value, they may prove eventually to be of considerable importance.

LOCATION.

The phosphate deposits described in this progress report[a] are situated in southeastern Idaho and adjacent portions of Wyoming and Utah. The area examined during 1909 comprises parts of Bear Lake County, Idaho, Uinta County, Wyo., and Rich, Weber, and Morgan counties, Utah. The location of the areas covered by the special maps accompanying this report is shown on the index map (fig. 42), page 484.

Other important districts will doubtless be examined and mapped in continuation of the present work; among these may be mentioned the deposits near Paris Canyon, Bloomington, Swan Lake, and Soda Springs, in Idaho, and the supposed extensive fields in Wyoming of which no complete review has yet been made.

[a] It is expected that a more complete report will be issued after further field examinations now contemplated.

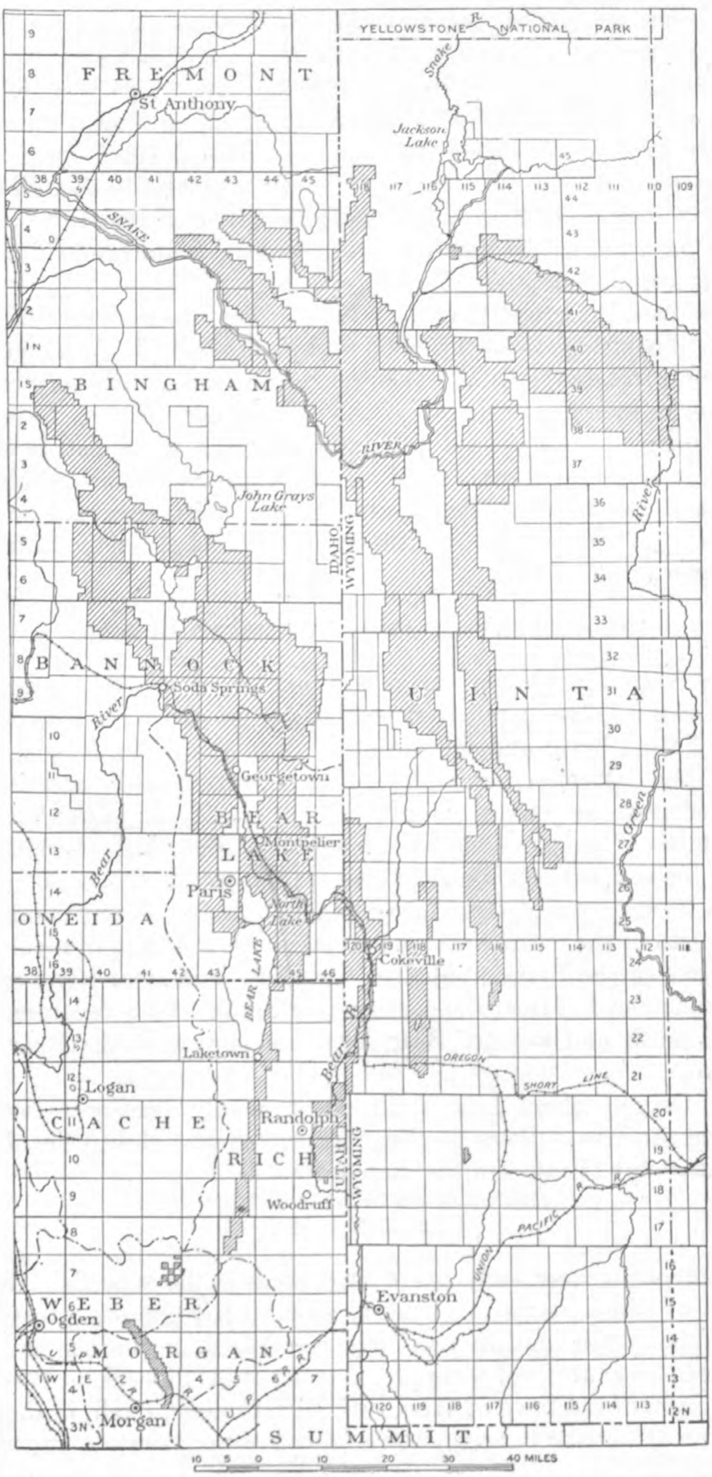


FIGURE 41.—Map showing extent of phosphate reserve of Idaho, Utah, and Wyoming, May, 1910.

The actual limits of these phosphate deposits are not yet known. Phosphate was found by the senior author in the Park City formation in Big Cottonwood Canyon near Salt Lake City. Specimens collected by Boutwell from the Park City formation in the Park City mining district have recently been recognized and identified by chemical test as phosphate rock. This rock is also reported to occur on Mill Creek, southeast of Salt Lake City, where float is said to have been found on a hill to the north of the wagon road above the limekilns, near the main road.

Phosphate rock is reported in Provo Canyon at or near Midway, Utah. Specimens from supposed coal prospects of the same geologic horizon, on Labarge Creek, Wyoming, and from supposedly equivalent rocks east or southeast of the Wind River Range, have been tested, showing phosphate and indicating the wide distribution of these deposits. The extent of similar deposits southward through Utah and possibly into Nevada is suggested. The supposed northern extension of the deposits is outlined by the area of land withdrawals, as shown in figure 41.

GEOGRAPHY OF AREA EXAMINED IN 1909.

The Preuss Range, in the northern part of the area examined, shows the maximum relief, the difference in elevation between the level of Bear River and the top of Mead or Preuss Peak being 4,000 feet. The extreme relief in the southern portion of the area is 1,700 feet, between the level of Bear River and Rex Peak, in the Crawford Mountains. The mean surface elevation of Bear Lake is 5,925 feet above the sea, as determined by recent level work.

The flood plains of Bear River and Bear Lake occupy one-fifth to one-fourth of the entire area; the remainder is made up of mountains, consisting of the Preuss, Sublette, Crawford, and Bear River ranges. The upland east of Bear Lake, extending to the Idaho-Wyoming line, to the south and west of Bear River, is known as the Bear Lake Plateau.

The Oregon Short Line Railroad, the only transportation line crossing the area, follows the Bear River valley. Montpelier, Idaho, and Randolph, Utah, are the largest towns.

EARLIER WORK.

The deposits were early prospected because the superficial resemblance of the outcrop to coal blossom attracted the prospector. Their phosphatic nature was first recognized, according to C. C. Jones,[a] in an analysis of a sample taken by R. A. Pidcock on Woodruff Creek, west of the town of Woodruff, Rich County, Utah, in the sum-

[a] Eng. and Min. Jour., vol. 68, 1907, pp. 953-955.

mer of 1897. The true nature of the deposits having been found out, the work of the discouraged coal seekers became of value to the phosphate prospector—a fact which explains the rapidity with which a large portion of the easily accessible deposits were located. Mr. Jones took a prominent part in this early staking out of claims and his paper gives a review of his methods and results.

Weeks and Ferrier[a] in 1907 published a general account of the western phosphate area, with brief descriptions of several of the localities.

In 1908 Weeks[b] published a progress report on his field work in the area, noted the progress of the industry, and discussed the question of markets and the status of phosphate deposits in mining law.

NATURE AND ORIGIN OF THE ROCK PHOSPHATE.

ORIGINAL SEDIMENTARY DEPOSITS.

The rock-phosphate deposits of the Idaho, Utah, and Wyoming fields are original sedimentary formations laid down at the time when that part of the earth's surface was largely covered by water. Since the time in which the phosphatic strata were deposited other rock-forming sediments have been accumulated, so that many thousands of feet of subsequent strata have overlain or succeeded them. Deformation of the earth's crust has tilted, folded, and frequently broken these strata, which originally lay flat. Uplift of the land or recession of the sea has subjected the rocks in their disturbed positions to stream erosion and the action of atmospheric agencies, so that great bodies of the more elevated parts have been removed entirely and the truncated edges of the rock strata are now exposed at the surface. The occurrence of the rock phosphate at the surface of the ground now depends on the geologic structure and more or less accidental relationships, such as absence of masking cover of later deposits, depth of erosion, and many minor factors.

The rock-phosphate deposits are thus more properly analogous to coal and limestone and especially to the Clinton iron ores of the Appalachian region than they are to ore deposits such as veins or lodes or to alluvial deposits of the placer type.

SOURCE OF PHOSPHORIC ACID.

An entirely satisfactory explanation has not yet been given of the source or manner of accumulation of the phosphoric acid. Phosphorus in combined form is one of the mineral constituents in the earth's crust, as it is found in nearly all igneous rocks, generally in

[a] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in Western United States: Bull. U. S. Geol. Survey No. 315, 1907, pp. 449–462.

[b] Weeks, F. B., Phosphate deposits in Western United States: Bull. U. S. Geol. Survey No. 340, 1908, pp. 441–448.

the mineral apatite. It is also found in some meteorites. It is an essential ingredient of living matter, especially of bones. It is present in sea water in the form of phosphates. The phosphatic concretions found on the ocean floor are explained as derived from the decaying bones of dead animals, upon which carbonic acid exerts a powerful solvent action. They form around various nuclei, but preferably upon organic centers, such as shells. These concretions consist mainly of calcium phosphate and carbonate mixed with sand and clay. They have been found on the ocean floor at a depth of 1,900 fathoms (11,400 feet).[a]

As pointed out by Clarke,[b] deposits formed by accumulations from decaying animal remains on the ocean bottom are at best but moderately phosphatic. It seems likely that concentration is usually effected under subaerial or alternating shallow water and land conditions, where atmospheric agencies begin to work on these remains. The soluble carbonates being removed by surface or ground waters, the relatively less soluble phosphates remain, mixed with more or less residual sand and clay.

The conditions favoring the vast accumulation of organic matter during a particular epoch of the Carboniferous period are not explained. Some indications that shallow water conditions prevailed during the deposition of the phosphate beds are found in the ripple-marked layers associated with those beds in a few places. The great lateral extent and uniformity of the deposits indicate uniformly widespread conditions effecting their deposition. The abundance of fossil shells in the phosphatic series is also evidence of marine shallow-water conditions.

DESCRIPTION OF THE ROCK PHOSPHATE.

The rock phosphate itself is chiefly characterized by an oolitic texture, by which it can usually be recognized in the field. Rounded grains, built up in roughly concentric structure, range in size from the most minute forms visible to the naked eye or by the hand lens to pebble-like bodies half an inch in diameter, rarely larger. In unaltered specimens there is commonly no visible or distinct cementing of the oolitic grains, except where they occur scattered in a groundmass of foreign material. In the weathered condition, however, as the material is commonly found near the surface, the grains have a grayish color and are more or less distinct. The rounded ovules are also characteristically distinct on weather-polished bedding planes of the more oolitic rock.

The rock phosphate varies in color from coaly black, as at Montpelier and at Woodruff Creek, where it was originally mistaken for

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, pp. 18, 92, 104, 447-451.
[b] Idem, p. 448.

coal at many places along its natural outcrop, to dull gray or iron stained, as in the Beckwith Hills. Its float is characteristically marked with a thin film of bluish-white bonelike coating, resembling chalcedony, in places with reticulated markings; this is thought to be some secondary phosphatic mineral but has not yet been studied. This coating is useful in tracing the concealed outcrop in the field by means of scattered float or fragments to be found in the overlying soil. A dark indigo-blue stain which proved to be fluorite on examination in thin section was observed in some of the beds at the Cokeville mines, but it is not known that this stain has any general significance in relation to the phosphatic composition of the material. The black color which is common in these deposits is thought to be due to bituminous matter, not necessarily bearing any relation whatever to the phosphoric acid content of the rock, as the phosphate salts related to the substance in this rock are probably white or colorless when pure.

Most of the phosphatic rock has, when broken or struck, a fetid odor, which is supposed to be characteristic of these minerals. The limestones associated with the phosphate beds show this same character, and experience does not seem to justify the inference of any direct relation between the amount of the fetid odor given off and the grade of the phosphate rock. Many of the limestones, which have the odor most strongly, contain only a very small percentage of phosphoric acid. It is to be noted that other limestones show this same character, notably those occurring in the Niobrara formation in the Cretaceous section of the Denver region and elsewhere.

SPECIFIC GRAVITY.

The specific gravity of representative specimens of the high-grade ore from several localities was determined for use in computing estimates of tonnage. The first determinations were made with a Jolly balance and the results obtained are as follows:

Specific gravity of specimens of rock phosphate.

Field No. of specimen.	Source.	P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Specific gravity.	Average specific gravity.
		Per cent.	*Per cent.*		
3	Montpelier, Waterloo claim, massive ore (two chips).	38.3	83.9	2.93 2.89	2.91
92-D	Crawford Mountains, Sioux claim (two chips)........	35.7	78.2	2.86 2.94	2.90
94	Crawford Mountains, Arickaree mine (two chips)....	37.7	82.6	2.92 2.95	2.93
130-C	Ogden River area....................................	31.8	69.6	2.89	2.89
	General average....................................	....	....	....	2.91

Other determinations on larger blocks of similar material were made by W. T. Schaller, in the laboratory of the United States Geological Survey, as follows: A specimen of compact phosphate rock (high-grade ore) from the mines of the Union Phosphate company, near Cokeville, Wyo., weighing 493.7 grams, gave a density of 2.92; a specimen of compact phosphate rock (high-grade ore) from the Waterloo mine of the San Francisco Chemical Company, near Montpelier, Idaho, weighing 707.5 grams, gave a density of 2.86. For these determinations the specimens were coated with paraffine before being weighed in water, to prevent absorption of water into the mass of the rock.

As a result of the foregoing tests it is probable that the density of the more massive ore of 70 per cent grade or over (tricalcium phosphate equivalent) from this general region is without much doubt between 2.85 and 2.95; an average of 2.90 has been assumed for the tonnage calculations. From this ratio the weight of a cubic foot of the more massive rock phosphate similar to that now being shipped from the mines in this region is about 180 pounds.

CHEMICAL COMPOSITION.

The chemical composition of the rock phosphate offers a somewhat mooted and a difficult question. Thin sections of the richest ore show under the microscope that the rock consists mainly of ovules or concretions of a cryptocrystalline substance which, in some concretions, is surrounded by banded zones of crystalline fibers with local isotropic bands, all having the same average index of refraction (1.60) and apparently representing the same substance—the phosphatic mineral. In some places the interstices are filled with calcite and in others with an isotropic material which appears to be identical with the substance comprising the cores of the concretions. Specks of purple fluorite are also found in the interstitial material in the slides of the rock from the Cokeville district. The phosphatic mineral includes minute curly, hairlike, and branching plant fragments whose appearance strongly suggests that they represent fungi. The extinction of the double refracting mineral is parallel to the elongation of the fibers and its optical character is apparently negative. Both of these properties are possessed by the mineral apatite, which, however, has a slightly higher index of refraction and a higher specific gravity.

The following more complete analyses of phosphate rock from these fields were made by George Steiger in the laboratory of the United States Geological Survey:

Analyses of phosphate rock from Wyoming, Utah, and Idaho.

	1.	2.	3.	4.
Insoluble	10.00	1.82	9.40	2.62
SiO_2	None.	.30	Not det.	.46
Al_2O_3	.89	.50	.90	.97
Fe_2O_3	.73	.26	.33	.40
MgO	.28	.22	.26	.35
CaO	45.34	50.97	46.80	48.91
Na_2O	1.10	2.00	2.08	.97
K_2O	.48	.47	.58	.34
H_2O	1.04	.48	.61	1.02
H_2O+	1.14	.57	.75	1.34
TiO_2	None.	None.	None.	None.
CO_2	6.00	1.72	2.14	2.42
P_2O_5	27.32	36.35	32.05	33.61
SO_3	1.59	2.98	2.34	2.16
F	.60	.40	.66	.40
Cl	Trace.	Trace.	Trace.	Trace.
Organic matter	Not det.	Not det.	Not det.	Not det.
	96.51	99.04	98.90	95.97

1. Main phosphate bed, 2½ miles east of Cokeville, Wyo.
2. Dunnellon claim, Crawford Mountains, Utah.
3. Elsinore claim, Tunnel Hollow, between Morgan and Devils Slide, Utah.
4. Preuss Range, 8 miles east of Georgetown, Idaho.

Qualitative examination of the insoluble matter indicates that it consists mainly of silica with minor amounts of kaolin. Quartz was not observed in thin sections of the high-grade ore. The CO_2 in some of the rock is apparently nearly all combined with lime in the form of calcite, as is indicated by the presence of the mineral in the sections and the fact that the gas is liberated on treating the powdered rock with dilute acetic acid; but elsewhere it is probably combined in some other way, because calcite is absent in thin sections and the gas is not liberated on treatment of the powder with the acid but comes off when hot dilute HCl is used. The nature of such combination is problematical, but it is possible that the CO_2 may be present in a phosphatic mineral of the nature of podolite ($3Ca_3(PO_4)_2.CaCO_3$). The SO_3 may be combined with some of the lime, as gypsum or more probably anhydrite, and both minerals have been noted as present in streaks in the lower-grade rock at an exposure in the NW. ¼ SE. ¼ sec. 8, T. 11 N., R. 8 E., in the Crawford Mountains, Utah, but have not been seen in the microscopic examination of the high-grade rock. Another alternative might lie in regarding the SO_3 as combined with the alkalies, of which soda is present in an average percentage of 1.5. However, no indications of such compounds are noted under the microscope. A recalculation of the analyses given above, after the alkalies and SO_3 and enough of the lime as calcite to satisfy the CO_2 have been removed, appears to suggest that the calcium phosphate mineral closely approximates in composition a basic calcium phosphate—probably more basic than apatite because of the absence of the haloids—to which further investigation may warrant the assignment of a new mineral name. By some authorities it is reported, however, that chemical examination of rock phosphates from other fields has "shown indubitably that these phosphatic bodies are members of a series of solid solutions of phosphoric acid in lime." The substance of the rock phosphates of South Carolina, Florida, and Tennessee, "like the coprolites, osteolites, phosphorites, etc., found in more limited quantities in various parts of the world, seems to be an amorphous body containing lime and phosphoric acid in proportions varying more or less from that required by the formula for tricalcium phosphate, and always mixed with some calcium carbonates."[a]

FIELD DETERMINATION OF PHOSPHORIC ACID.

The desirability of having immediate determinations of the phosphoric acid content of the ores during the field examination led to a cooperative arrangement with the Bureau of Soils by which a chemist of that bureau was detailed with the Idaho party. A special outfit was designed for the chemical work, consisting of compact and durable apparatus; porcelain ware was substituted for glassware where feasible; the chemicals were, so far as possible, carried in solid form for convenience in transportation; distilled water was obtained by means of a simple form of copper still, which was operated in connection with the camp range.

In general, the samples were collected by cutting a channel across the face of the phosphatic beds, or where that was not feasible, by chipping representative pieces from the clean surface, starting at the upper part of the bed and working down toward the base, care being taken to keep the chips of a size approximately proportionate to the part of the bed they represented. The lithologic characters were used in determining the part of a face to be included in a sample; for example, if the upper foot of a bed consisted of coarsely oolitic material it was sampled as a unit and its phosphatic content determined; if the next lithologic interval of the bed was shaly, that portion was sampled as another unit, etc. Occasionally average samples were taken in order to get the average content of the bed and as a check on the determinations made for the several units. It was found in the progress of the work that it was possible in this way to locate the distribution of the high-grade and low-grade materials in the beds. The field determinations of the phosphoric acid are quoted with the several sections of the phosphate beds given in the text and on the plates accompanying these reports, and the following description of the field methods of analysis employed is quoted in full from a report of that work to be issued by the Bureau of Soils:[b]

The weight of the samples ranged from one-half pound to 4 pounds, depending on the thickness of the beds. Each sample was crushed on the small bucking board, quartered down, pulverized in the small porcelain mortar, and finally put through the

[a] Cameron, F. K., and Bell, J. M., The action of water and aqueous solutions upon soil phosphates: Bull. 41, U. S. Dept. Agr., Bur. Soils, p. 9.

[b] Waggaman, W. H., Bull. 69, Bur. Soils, U. S. Dept. Agr. (In press.)

sieve. During damp weather, or when the samples were collected from prospects wet from percolating water, they were dried in an oven, but in these normally dry regions this was seldom necessary.

Two grams of the sample were weighed and brushed into an enameled cup; 25 to 30 c. c. of water (not distilled) were added and 10 c. c. of concentrated nitric acid. The cup was covered with a watch glass, placed on the stove, and the contents allowed to digest for seven or eight minutes. After cooling somewhat, the insoluble material was filtered off, washed thoroughly on the filter, and the filtrate made up to 200 c. c. with water (not distilled). An aliquot (10 c. c. or 20 c. c., depending on the amount of P_2O_5 present) was then taken for analysis. This was diluted with 20 to 30 c. c. of water, a few cubic centimeters of saturated solution of ammonium carbonate added, and sufficient nitric acid to render the solution acid to litmus paper. The cup was then returned to the stove, heated to 70° or 80° C., and 25 c. c. of ammonium molybdate solution added, drop by drop, with constant stirring. After standing ten minutes the solution above the precipitate of ammonium phospho-molybdate was decanted and filtered and the precipitate washed as far as possible by decantation until the washings gave no acid reaction. Distilled water was used in this last operation. The filter was then returned to the cup, a little distilled water was added, and a standard solution of potassium hydroxide was added until the yellow precipitate dissolved. Standard nitric acid (matched against the potash solution) was run in from a burette, drop by drop, until the pink color of the indicator—phenolphthalein—disappeared. The quantity of nitric acid used, subtracted from the amount of potassium hydroxide, gave the number of cubic centimeters of the latter solution required to dissolve the yellow precipitate. The potassium hydroxide was of such strength that 1 c. c. equaled 1 milligram of phosphoric acid (P_2O_5). This solution was standardized against acid potassium sulphate ($HKSO_4$). The latter being a solid can be readily transported without danger. Definite charges were weighed out in the laboratory before starting for the phosphate area, and these were made up to 200 c. c. as required. When the solution from a 2-gram sample of phosphate is made up to 200 c. c. and 10 c. c. aliquots are used for analysis, all calculations are avoided, for the percentage of phosphoric acid present is the same as the number of cubic centimeters of potassium hydroxide necessary to dissolve the precipitate. If a 20 c. c. aliquot is taken, the amount of potassium hydroxide employed, divided by 2, gives the percentage of phosphoric acid present.

It was found that after the samples were quartered down, it was possible to run through twenty determinations during the day. The results could usually be duplicated within 0.2 of 1 per cent of the actual quantity of phosphoric acid present.

The field chemical determinations quoted throughout the text of this report show the percentage of phosphoric acid contained in the specimens collected, and these have been arbitrarily recalculated to the tricalcium phosphate basis, as that is a factor of comparison in common use in commercial practice.

IRON AND ALUMINA.

In the manufacture of superphosphates the raw rock phosphate is treated with sulphuric acid and the resulting product is then dried to be used as fertilizer direct or for mixture in combined or compound fertilizers. It is said that in factory practice the product of the acid-treatment process sometimes remains moist and gummy, so that it is difficult to handle, a property which would also interfere seriously with the uses to which the material is put. Iron and alumina are supposed to be the cause of this undesirable property in the manufactured product, as their sulphates show a tendency to take up moisture in a damp atmosphere.

Relatively few iron and alumina tests have been made in connection with the present investigation, as it appears to be generally conceded that the phosphate of these western fields does not contain these elements in objectionable amount. The percentages quoted in the foregoing table (p. 465) are probably indicative of what the general average would be. Each specimen tested shows less than 1 per cent of either radical computed in the usual oxide form.

ENRICHMENT BY WEATHERING.

A tendency toward enrichment of the content of phosphoric acid is shown in the weathered outcrops of the rock-phosphate beds. As this is what would naturally be expected from the chemical constitution of this material, no extensive investigation of it has been undertaken. An average sample from a partly weathered face in the open-cut quarry on the Waterloo claim at Montpelier was tested, showing 38.0 per cent of phosphoric acid, equivalent to 83.2 per cent of tricalcium phosphate; another average sample of the same bed taken from a fresher face about 50 feet in on the lower entry of the mine gave 34.8 per cent of phosphoric acid, equivalent to 76.2 per cent of tricalcium phosphate; and still another near the north end of the lower entry showed 33.7 per cent of phosphoric acid, equivalent to 73.8 per cent of tricalcium phosphate. This evidence is probably insufficient on which to base general conclusions as to the amount of such enrichment, but the deeper mining operations in various parts of the field seem to have demonstrated that fresh rock from the thicker workable beds usually maintains an average content exceeding 32 per cent of phosphoric acid, which would be equivalent to 70 per cent or over of tricalcium phosphate.

This tendency toward enrichment is readily explained as the result of the leaching by surface or upper ground waters of the more soluble calcium carbonate and possibly other salts, so that the less soluble calcium phosphate is concentrated in the residuum.

No allowance for this factor has been made in the interpretation of the general sections that have been tested, although on account of the weathered condition of many of the samples taken there can be little doubt that a large number are rather above the normal content than truly representative of the beds in depth.

GEOLOGY.

STRATIGRAPHY.

GENERAL STATEMENT.

In a practical discussion of the stratigraphy of the rock-phosphate deposits emphasis is naturally placed on the description of the rocks most directly associated with the phosphate-bearing strata. Recognition of the character and details of the rock formations overlying and underlying the economically valuable beds has a more or less important bearing in the study of these deposits themselves, for it is largely by means of these details that the beds themselves may be identified or traced along their outcrops or estimates may be made of their depth where they pass below the surface. Areas occupied by rocks older than the phosphate would not normally be considered as phosphate land, but some areas where the stratigraphic section is completely overturned furnish exceptions that must be recognized by means of the geologic structure and details of succession in the stratigraphy.

TABULAR SUMMARY.

A general summary of the stratigraphy of the rocks most directly related to the phosphate beds in the areas that have been studied is given here in brief tabular form. These formations are also described in somewhat greater detail in the following pages, where some of the more complete and detailed sections obtained in the present work are reviewed, as these sections are representative of the more important evidence from which the generalized statements are made.

Summary of that part of the stratigraphic section most directly related to the phosphate deposits of southeastern Idaho.

Geologic age.	Formation.	Thickness.	Description of strata.
Tertiary (Eocene).	Wasatch group.	Not measured (probably several thousand feet).	Includes a considerable thickness of roughly bedded coarse sandstones, clays, and coarse conglomerate or bowlder beds, in places of a deep-red color in the lower part, succeeded by a series of light or pale varicolored clays or marls, with white, locally coarsely oolitic limestones.
Unconformity.			
Cretaceous.	Bear River formation.	Not measured.	Dark shale, sandstone, conglomerate, and some limestone. Contains beds of impure coal near Cokeville.
Jurassic-Cretaceous.	Beckwith formation.	No complete measurement.	A thick formation including coarse conglomerate, white to yellowish calcareous sandstone, and sandy shale. Characteristically exposed at the north end of the lower Thomas Fork valley.

Summary of that part of the stratigraphic section most directly related to the phosphate deposits of southeastern Idaho—Continued.

Geologic age.		Formation.	Thickness.	Description of strata.
Jurassic.		Twin Creek limestone	About 3,500 feet at the type locality.	Consists mainly of limestone, mostly thin bedded or shaly, with some massive strata, which characteristically weather in bluffs or bare wash slopes of white, splintery, shalelike material. Forms the high ridge between upper Montpelier Creek and Thomas Fork valley and is elsewhere prominently exposed.
Jurassic or Triassic.		Nugget sandstone.	1,900 feet in Raymond Canyon.	Massive red and white sandstone and red sandy shale. The greater part is of dark-red or brown color, although in places an upper zone is distinct as a clear white sandstone. Includes intervals of sandy shale, which are, however, generally obscured in outcrops by talus of the harder rock. Forms prominent ridges throughout the Montpelier district.
Triassic or Carboniferous (including the Middle and Lower Triassic of Hyatt and Smith.[a]		Ankareh shale.	670 feet near Montpelier.	Consists essentially of red shale and mottled red and greenish clay and shale with some sandstone and ilmestone.
		Thaynes limestone.	About 2,000 feet or less.	The main body of the formation consists of dark-blue limestone, in many places fossiliferous, weathering to a brown muddy color, also including sandy and calcareous shale.
		Woodside shale.	1,000 feet in the Preuss Range.	Chiefly shales; generally red in the upper part, with the base usually composed of shaly limestone, weathering rusty brown.
Carboniferous.	Pennsylvanian.	Park City formation.	600 ± feet.	A formation including three divisible units, as follows: (a) One or more massive strata of cherty limestone, prominent as a ledge maker. (b) Rock phosphate, phosphatic shale, and minor limestone bands. (c) Limestone, massive, usually light bluish, granular weathering, and in some localities containing abundant black chert in rounded nodules.
		Weber quartzite.	1,000 ± feet.	Massive white quartzite, locally rather calcareous, with minor limestone beds and sandy shale forming transition zones near the top and base.
	Mississippian ("Wasatch limestone" of King, in part).	(a) Limestone, not distinguished from the Madison limestone in the present work. Collections from the extreme northern part of the area studied show an upper Mississippian fauna, younger than that of the Madison. (b) Madison limestone.	(?)	Massive blue limestone, a thick formation usually making high mountainous country where brought to the surface in mass; exposed in dark blue or black weathering ledges, locally marked by fossil corals. Forms west slope of Preuss Range from Joes Gap south to Limekiln Hills at Montpelier. Contains phosphatic beds in the Ogden area. (See p. 85.)

[a] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

DETAILED DESCRIPTIONS AND SECTIONS OF FORMATIONS.

GENERAL SECTIONS.

Several general sections and one detailed section of the rocks overlying the Park City formation have been measured in various parts of the area. In these sections, as with the rocks underlying the phosphate deposits, attention has been directed chiefly to the rocks most directly associated with the special interests of this work, and the following discussion is limited to those rocks which were found important in the recognition of position or depth of the valuable deposits, with a study of stratigraphic thicknesses. The fossils associated with the phosphate beds and found in the overlying strata are in many places valuable guides in determining the position and depth of the phosphate below the surface. If the phosphate beds lay in their original horizontal position, with the succeeding formations in normal sequence above them, then the stratigraphic thickness of the overlying beds would give the measure of depth from the surface to the phosphate. Where the strata are tilted or folded and the various formations are exposed by erosion the factors of dip and identification of the horizon at the surface form the basis for computation of position and depth of the phosphate zone.

The best general section obtained was that in Raymond Canyon, which crosses the Sublette Range and cuts the steeply dipping strata nearly at right angles to the trend of those mountains and the strike of the rocks. This gives the following general intervals:

Stadia measurement of the Raymond Canyon section, Sublette Mountains, Wyoming.

		Feet.
Twin Creek limestone: Limestone, white, weathered, splintery, fractured, shaly, and massive (not measured).		
Nugget sandstone:		
Sandstone and quartzite, very massive, dark red and brown, forming heavy talus slopes	1,700	
Sandstone, massive, and sandy shale, with heavy ledge of conglomeratic white quartzite at top	200	
		1,900
Ankareh shale: Mostly shaly beds, dark-red and maroon shales, and some massive sandstone (not well exposed)		700
Thaynes limestone:		
Limestone ledges, very massive, muddy and rusty weathered surface, forming steep, rocky canyon walls	1,300	
Interval, limited by massive limestone ledges at top and bottom, covered by brown weathered limestone talus and containing some massive limestone strata	800	
		2,100
Woodside shale (upper limit not defined; probably should include some higher beds): Largely concealed by talus of limestone from harder ledges, but including some thin-bedded limestone and shaly beds (not well exposed)		600

		Feet.
Park City formation:		
Cherty limestone, very massive ledge, single stratum	80	
Interval entirely concealed by talus except where opened in phosphate prospects	200+	
Limestone, white, granular, weathered ledges grading into quartzite	300	
		580+
Weber quartzite: Quartzite, white, calcareous and sugary texture in part (measurement omitted because it was not complete).		
Total section as measured		5,880

Another good section is to be had in the hills east and northeast of Hot Springs, near Bear Lake, Idaho. The measurements obtained at this place are as follows:

Stadia measurement of section near Hot Springs, Idaho.

		Feet.
Twin Creek limestone: Limestone, white, shaly, with some massive ledges (incomplete section).		
Nugget sandstone: Sandstone, red and white, quartzitic, massive, thick-bedded		2,000
Ankareh shale: Shale, dark red, maroon and iron stained, with massive blue limestone at top		700
Thaynes limestone: Limestone, rusty brown or muddy weathered on surface, many massive ledges		1,900
Woodside shale: Interval concealed, probably of shaly beds		800
Park City formation:		
Chert, black, massive, roughly bedded	110	
Shale, phosphatic, and phosphate beds	275	
Limestone, white, sandy, massive ledges	200+	
		585+
		5,985+

The section of the rocks immediately overlying the phosphate beds in Montpelier Canyon, 1 to 4 miles east of the town, was examined in much detail, with special reference to the paleontologic data to be obtained from it. The fossil collections made have not yet been completely studied.

Stratigraphic section of beds overlying the Park City formation in Montpelier Canyon, Idaho.

[By C. L. Breger.]

	Feet.
Mississippian:	
17. Limestone, massive, brecciated, and cherty (overthrust).	
Thaynes limestone (2,200+feet):	
16. Shale, gray, thin; like 14; limestone lenses up to 4 feet thick, in many places crowded with terebratuloids	210
15. Limestone, brownish, thick bedded; with terebratuloids	40
14. Shales, gray to olive, thin; with scattered limestone lenses up to 15 feet thick. Rayed pectinoids abundant locally. Terebratuloids and *Pugnax utah* Marcou? abundant in some of the limestones	656

Thaynes limestone—Continued.	Feet.
13. Sandy limestones and calcareous sandstones, the latter thick bedded; upper portion produces brown-weathering talus slopes	574
12. Limestones, forming a conspicuous horizon marker recognized as far south as the Woodruff area in Utah; the basal 10 to 15 feet crowded with terebratuloids. Rayed pectinoids and *Pugnax utah* Marcou? also occur at the base as well as higher.	
11. Interval, covered; includes some thin gray shales	83
10. Sandstones, locally calcareous and forming brown-weathering talus slopes; contains *Bakewellia* (?); some purer limestone bands or lenses up to 15 feet thick are in places charged with terebratuloids and some *Pugnax utah* Marcou?	216
9. Interval, mostly covered; includes some gray shales	379
8. Limestone, light colored, resistant; the *Meekoceras* zone of Peale, White, Hyatt and Smith, etc.; a well-defined horizon marker from Hot Springs northward; exposed	39
Woodside shale (1,000+feet):	
7. Limestone, like 8 but somewhat darker, containing *Myalina* in abundance	55
6. Sandstone, gray, shaly below	87
5. Shales and thinly laminated sandstones, gray and red, the whole forming a red-bed member which furnishes a persistent horizon marker	198
4. Sandstones, light colored, shaly below, quarried for building stone at top, contains large *Myalina*	200
3. Limestones, gray, blue, thin bedded, with a couple of massive bands, the whole forming a conspicuous horizon marker. Fossils at base—small lamellibranchs, including a small smooth pectinoid	48
2. Shales, gray; with thin-bedded limestone seams and bands, pale cocoa-brown in color	235
(1 and 2 contain chiefly *Lingula*, with some obscure lamellibranchs.)	
1. Interval, covered, like 2; thickness roughly estimated, possibly more than 150 feet	150
Productus or cherty limestone at top of Park City formation.	

MISSISSIPPIAN AND OLDER ROCKS.

The rocks underlying the Weber quartzite in the normal succession include a great thickness of Mississippian and older Paleozoic limestones which were preceded by a series of quartzites and shales. These in turn rest on pre-Paleozoic quartzites, shales, and slates and metamorphic gneisses and schists. This limestone series, which includes in places some Ordovician rocks, is more or less completely exposed in several of the areas studied, notably in the Crawford Mountains, at the head of Woodruff Creek, near Laketown, and along the crest of the Preuss Range east of Georgetown. Smaller areas, presumably of Mississippian limestone, occur at the west foot of the Sublette Range in the anticlinal axis east of Cokeville and in the overthrust mass of these rocks east and northeast of Montpelier. It seems probable that the limestone series described above should be correlated with the "Wasatch limestone" of the Wasatch Mountains in Utah. As defined by the Fortieth Parallel Survey the "Wasatch limestone" contained representatives of the Carboniferous (both Pennsylvanian and Mississippian), Devonian, and Silurian systems. The Pennsylvanian and upper Mississippian portions of the "Wasatch limestone" are not represented in the areas examined so far as evidence has been obtained, except at one point where a small collection supposed to be of upper Mississippian age was made.

The suggestion that the name Madison limestone be applied to the lower Mississippian portion of the "Wasatch limestone" of the earlier surveys as it occurs in the area examined is made by G. H. Girty, thus connoting a correlation of these rocks with formations recognized and mapped in the Yellowstone National Park, the Bighorn Mountains, and elsewhere. Doctor Girty says:

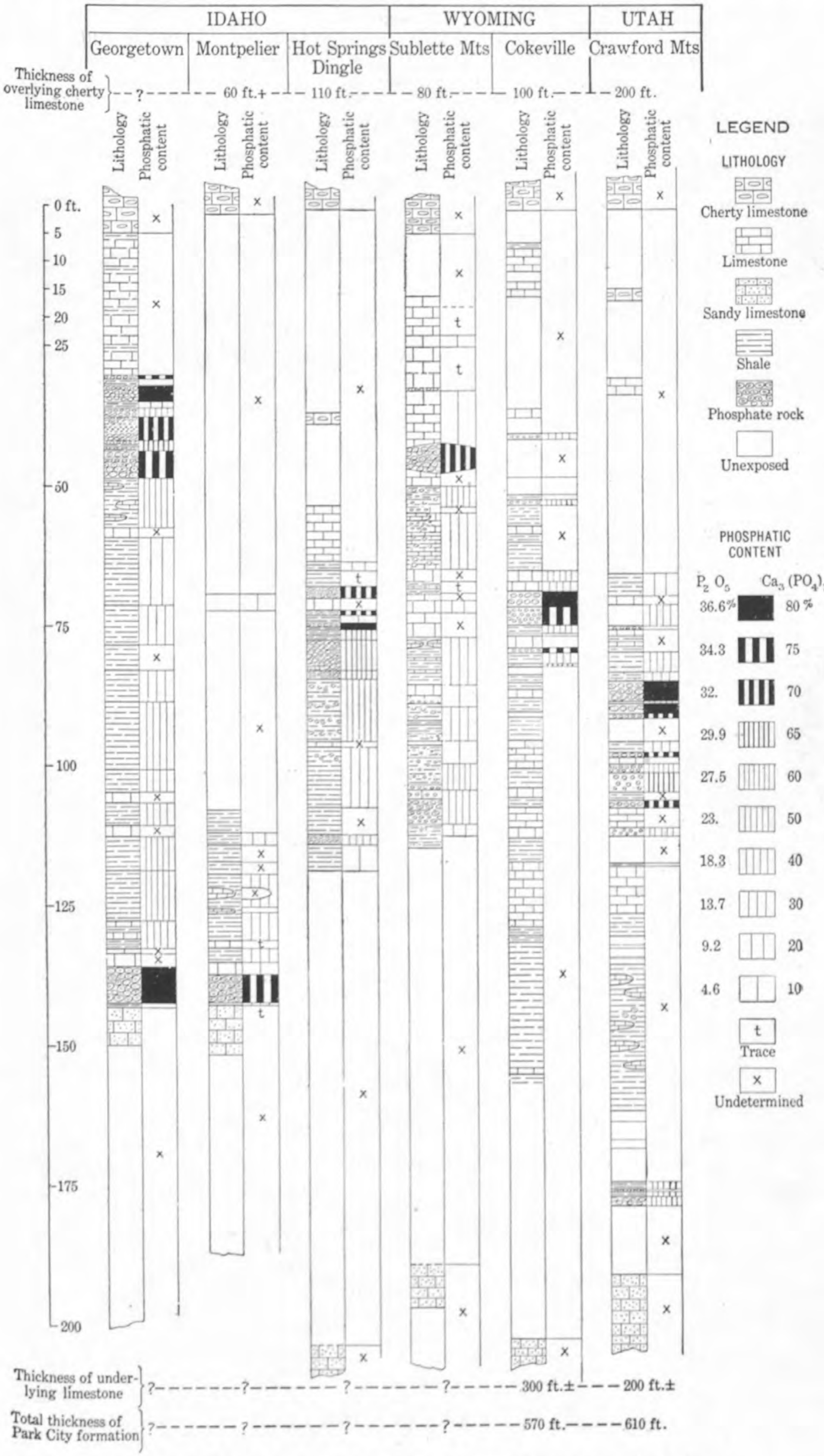
> The fauna of this formation has a wide distribution in the West and always occurs in a limestone matrix. It is my belief that the different outcrops originally formed one continuous sheet. If attention be confined, however, merely to the general area in question [southeastern Idaho, etc.], the fauna is the same as that of the Madison limestone of Yellowstone National Park, and it seems very likely that the rocks themselves will trace directly into the typical Madison formation. In another direction the fauna is that of the basal Carboniferous portion of the "Wasatch limestone" of the Wasatch Range of Utah, and I have no doubt that these beds also were originally continuous. Of course, I am not prepared to say that the Madison in these different areas has exactly the same boundaries, or that through erosion or nondeposition beds are not lacking in one which are present in another section, but I believe that the content is essentially the same. It should be understood that Madison as here suggested includes only the lower Mississippian portion of the "Wasatch limestone." The middle or upper Mississippian part of the "Wasatch limestone" has not been recognized in the area studied by Mr. Gale's party last season except in the Swan Lake region.

Cambrian and pre-Cambrian rocks are extensively developed in the Bear River and Wasatch ranges, where they have been studied by Walcott and described in detail.[a]

WEBER QUARTZITE.

The Weber quartzite consists chiefly of massive white quartzite, but includes some shale and interbedded calcareous sandstone or limestone at both the top and the base. The thickness of this formation appears to vary considerably in different parts of the region, but about 1,000 feet may be assumed as an average. Uncertainty as to the exact definition of either its top or its bottom may give rise to the variations in the estimates obtained, and it has also been suggested that the formation includes an unconformity, perhaps at the top, but this hypothesis has not been substantiated by evidence in this field. It is difficult to determine the plane of division between it and the underlying limestone in this region, as the two

[a] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Inst. Misc. Coll., vol. 53, 1908, pp. 1-12; Cambrian sections of the Cordilleran area; Idem, pp. 167-230.



GENERALIZED COLUMNAR SECTIONS OF PARK CITY FORMATION.

apparently grade into each other by the alternation of sandstone or quartzite and limestone which has been referred to above.

The Weber quartzite forms no important or conspicuous exposures near the phosphate deposits studied in the present work, except at Cokeville and on the west margin of the Crawford Mountains, where the anticlinal fold revealed in the rocks underlying the phosphate is indicative of other outcrops to the west of those now recognized or opened by prospecting. The Weber quartzite is exposed in all the phosphate districts studied except near Montpelier, but its bearing on the occurrence or distribution of the valuable deposits is a relatively negative one, for, like the Mississippian and older rocks, it indicates that the phosphate beds are to be found away from it, in the direction of younger strata.

PARK CITY FORMATION.

The Park City formation was named in the Park City mining district, Utah,[a] where it is said to have contained the principal bonanzas for which that district is known. The correlation of this formation of the southern Idaho and northeastern Utah section with the rocks of the central and southern Wasatch region is based on faunal and lithologic correspondence between the sections of the two places; this similarity is indeed remarkable considering the distance by which the areas are separated. In the recent study of the phosphate beds, however, much more complete evidence of the continuity, especially of the beds associated with the phosphate, has been found, and the phosphate has recently been identified in the corresponding position in the Park City section. So exact is the lithologic correspondence that the thicknesses and descriptions given for the Park City district are almost directly applicable to the Idaho sections.

The Park City formation is divisible into three parts—an upper cherty limestone; an interval of phosphatic shales phosphate rock and limestone bands; and an underlying limestone, usually massive and commonly containing much chert.

The stratigraphic sections in Plate IV are compiled from numerous measurements of the Park City formation in each of the areas studied. Throughout the course of the work attention was directed chiefly to the study of the details of the phosphatic shale interval, in order to obtain data for possible correlation among the individual beds from place to place.

A massive ledge-forming stratum of chert or cherty limestone immediately overlying the phosphate-bearing shales is distinguished as a separate member, on account of its prominence and its value as a horizon marker from which to trace the outcrops of the phosphate

[a] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434-458.

beds themselves where they are not continuously exposed. This member has locally been referred to as "the cherty lime," "the *Productus* limestone," or "the overlying limestone." It consists of black chert and dark cherty limestones. It is quite distinct from the brown, shaly limestones of the lower part of the Woodside shale, overlying the Park City formation, and to a somewhat less degree distinct from the phosphate and phosphatic shales that underlie it, although in their upper part these shales include some cherty layers which are similar to this massive bed. The thickness of the massive cherty stratum was measured in several places where it was prominently exposed, showing at least 80 feet in Raymond Canyon, Sublette Mountains, Wyoming; 110 feet (probably total thickness) near Hot Springs, at the north end of Bear Lake, Idaho; from 125 to 200 feet at various places in the Crawford Mountains, Utah.

The cherty limestone overlying the phosphate contains some characteristic fossils, in the main species of *Productus*. Of these *P. semireticulatus* is most abundant; *P. humboldti* and *P. subhorridus?* are also present. In some beds *Spiriferina pulchra* and *Stenopora* are found in relatively greater abundance than *Productus*, being commonest in zones near the top of the cherty limestone.

The phosphate-bearing member of the Park City formation, including all the main phosphate beds, consists of 200 feet of massive brown to gray phosphatic shales and beds of rock phosphate, with some limestone and in places cherty bands in the upper part.

The occurrence of rounded or oval limestone nodules, ranging from a few inches to several feet in diameter, is a characteristic feature in the phosphate beds and the phosphatic shales. They consist of very dense, compact, fine-grained limestone, having a fetid odor when struck with a hammer, but showing a low percentage of phosphoric acid wherever tested. As all the dense, fine-grained limestones tested were found to run very low in phosphoric acid, tests of these rocks were abandoned in the latter part of the season's work.

Many detailed sections were measured in the phosphatic shales, especially in those immediately associated with the main phosphate beds. By reason of the weaker constitution of these shaly rocks they commonly give way to weathering and decay at the surface, and the outcrop is usually concealed as a whole or in greater part. Float of the harder rock phosphate remains in the soil and is very readily detected by one who has become familiar with its appearance and with the characteristic bluish-white chalcedony-like coating that forms on its exposed surfaces. Recent prospecting in the Georgetown Canyon district, which had opened a complete and continuous section across the entire formation at the time of this work, afforded rather exceptionally favorable opportunity for examination, measurement, and sampling. Practically the entire shaly section, 140 feet thick, was found on testing to be phosphatic. The beds that were sampled are indicated by numbers in the following section:

Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho.

Field No. of specimen.		Ft.	in.	P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness. Ft.	in.
				Per cent.	*Per cent.*	*Ft.*	*in.*
144-A	Shale, calcareous, or muddy limestone, brown, weathering into irregular chip fragments; effervesces vigorously			3.5	7.7	25	6
144-B	Phosphate rock, oolitic, weathering brown or gray; effervesces slightly; lower 1½ inches somewhat cherty			35.8	78.4		6
144-C	Shale, hard, brown, calcareous at the top; effervesces vigorously			Trace.	....	1	
144-D	Phosphate rock, coarsely oolitic, gray; effervesces vigorously			37.6	82.3	2	11
144-E	Shale, brownish, earthy, containing 6 inches of phosphate; effervesces considerably			10.0	21.9	1	
144-F	Phosphate rock, including—	*Ft.*	*in.*	21.9	48.0	1	5
	(*a*) Phosphate rock, oolitic, hard, gray, calcareous		7				
	(*b*) Phosphate rock, medium, gray, oolitic		6				
	(*c*) Shale, phosphatic, light brown		4				
	(Sample shows considerable effervescence.)						
144-G	Phosphate rock, including—			33.3	72.9	4	2
	(*a*) Phosphate rock, coarsely oolitic, gray, brittle	1	2				
	(*b*) Phosphate rock, finely oolitic, brownish gray		4				
	(*c*) Phosphate rock, coarsely oolitic, dark gray		2				
	(*d*) Phosphate rock, finely oolitic, brownish gray		4				
	(*e*) Phosphate rock, coarsely oolitic, gray		7				
	(*f*) Phosphate rock, finely oolitic, thin bedded		3				
	(*g*) Phosphate rock, coarsely oolitic, gray	1	4				
	(Sample effervesces slightly.)						
144-H	Phosphate rock, including—			29.3	64.1	1	10
	(*a*) Phosphate rock, medium to finely oolitic, brownish gray		7				
	(*b*) Shale, phosphatic, brownish, somewhat oolitic		10				
	(*c*) Phosphate rock, coarsely oolitic		2				
	(*d*) Phosphate rock, shaly, brown		3				
144-I	Phosphate rock, including—			34.7	76.0	4	10
	(*a*) Phosphate rock, coarsely oolitic, brownish-black streaks	1	1				
	(*b*) Phosphate rock, shale, brown, thin bedded		5				
	(*c*) Phosphate rock, coarsely oolitic, crumbly		4				
	(*d*) Phosphate rock, medium to coarsely oolitic	3					
	(Sample effervesces considerably.)						
144-K	Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses; effervesces slightly			24.2	53.0	8	9
	Limestone, dark, compact, fetid			....	....	1	9
144-L	Shale, brownish to black, earthy; effervesces slightly			11.7	25.6	12	
144-M	Shale, including—	*Ft.*	*in.*	15.1	33.1	17	1
	(*a*) Shale, brownish-black, earthy	7					
	(*b*) Concealed, not included in sample (probably same as *a* and *c*)	4	7				
	(*c*) Shale, brownish black, earthy	5	5				
144-N	Shale, black, earthy; effervesces slightly			19.9	43.6	12	
144-O	1. Shale, brownish black, earthy	4		21.2	46.4	12	
	2. Limestone, single stratum (not sampled)	2					
	3. Shale, brownish black, earthy	4					
	4. Limestone, single stratum (not sampled)	2					
144-P	Shale, black and dark brown, calcareous, earthy; effervesces considerably			25.8	56.5	6	2
144-Q	Shale, black, and dark brown, calcareous, earthy; effervesces considerably			24.6	53.9	12	
144-R	Limestone, shaly, brownish gray; effervesces vigorously			17.8	39.0	4	10
	Limestone, single stratum			....	....		11
	Limestone ("cap lime"), fine, dark gray, fossiliferous			....	....	2	3
144-S	Phosphate rock, main bed prospected, coarse to medium, oolitic, gray, contains two or three minor streaks of shaly material; effervesces slightly			36.8	80.6	6	4
144-T	Shale, brown, earthy; effervesces slightly			3.7	8.1		9
	Limestone, massive, underlying the phosphatic series. Thickness not determined.						
						139	11

The thickness of the phosphate-bearing members of the Park City formation varies somewhat, as shown by measurements obtained in other parts of the region. One or more cherty bands are found in the calcareous shale or muddy-weathering limestone at the top of the phosphatic series, making it difficult to define precisely the limits of the overlying cherty limestone. The phosphatic shales as measured include about 170 feet at Cokeville, Wyo., and average about 225 feet in the Crawford Mountains.

Fossils occur at many horizons in the phosphate-bearing members of the Park City formation, some well-preserved specimens having been found in the most massive beds of the rock phosphate itself. Some of the rounded limestone nodules occurring in the phosphate beds are fossiliferous. The main phosphate bed at Montpelier and in the Georgetown area is capped by a 2-foot ledge of dense, fine-grained dark limestone filled with exceedingly well-preserved fossils, from which excellent specimens have been obtained.

The distinction between the phosphate-bearing strata and the underlying limestones is clear in most places, but at its base the Park City formation consists of calcareous sandstone and bands of quartzite alternating with limestone, so that there is a transition into the more typical quartzite of the Weber.

The limestone underlying the phosphate-bearing strata in the Park City formation is usually massive and of sandy composition, occurring in heavy-bedded strata which weather with a light-bluish granular or sandy surface. White calcite in small, irregular crystalline patches is of rather common occurrence throughout this rock.

In the Preuss Range, in Montpelier and Georgetown canyons, this limestone contains much black chert in rounded nodular masses. The average thickness of the limestone is assumed to be about 300 feet, although no accurate determinations have been made. The cherty limestone beds forming the lower part of the Park City formation in Georgetown Canyon contain Pennsylvanian fossils.

WOODSIDE SHALE.

The Woodside shale immediately overlies the Park City formation and is so called by correlation with the section in the Park City mining district, Utah. It is composed mainly of shaly beds, mostly calcareous, usually showing as "red beds," in the upper part and of shaly or platy brown, rusty-colored limestone, and brown or gray shale in the lower part. It also includes some more or less massive limestones that are described as muddy, as they appear brown and earthy on weathering, being very similar in this respect to the limestones that characterize the overlying Thaynes. The base of the Woodside is quite distinct, for the upper cherty limestone of the Park City formation is usually well defined in contrast with the overlying shales. The upper limit of the Woodside is not so clear. As this formation was originally defined in the Park City district it was intended to include the reddish shaly beds and to be limited by the more massive limestones of the overlying Thaynes.[a] The distinction is perhaps not so clear in this field, but a more or less arbitrary limit may be drawn which corresponds closely with the descriptions and thicknesses given for the typical sections. Where it has been recognized the *Meekoceras* zone has been adopted as a paleontologic definition of the base of the Thaynes. In many sections studied *Meekoceras* is found in massive limestone succeeding a "red bed" shale interval 1,000 to 1,200 feet above the base of this formation.

THAYNES LIMESTONE.

The Thaynes limestone, overlying the Woodside shale in normal sequence, was named from its occurrence in Thaynes Canyon, near Park City, Utah. It contains marine fossil shells at many horizons, and from the occurrence of certain ammonoids (*Meekoceras*) at its base it has been assigned by Hyatt and Smith to the Lower Triassic.[b] The age of these fossils is, however, not yet proved. The Woodside shale, Thaynes limestone, and Ankareh shale were referred to the "Permo-Carboniferous" by the Fortieth Parallel Survey. The *Meekoceras* beds, where recognized by the Hayden Survey, were referred to the Triassic.

The Thaynes is distinguished chiefly by massive ledge-forming limestones which are in places abundantly fossiliferous. It also includes many shaly intervals and, to a minor extent, some brown-weathering calcareous sandstones that pass by gradations into the limestone. The limestone itself commonly contains a considerable percentage of clay and sand, so that on weathering it assumes a sandy or muddy aspect, making much of it difficult to distinguish from sandstone except on fresh fractures. The thickness of the Thaynes limestone is somewhat less than 2,000 feet as measured in Raymond Canyon, and the measurement obtained in Montpelier Canyon shows at least that thickness, but it is doubtless several hundred feet thinner at other localities from which measurements have been recorded.

ANKAREH SHALE.

The Ankareh shale of the Park City section was originally described from the exposures in Big Cottonwood Canyon, near Salt Lake City. This formation consists chiefly of clay shale of deep maroon and chocolate colors, massive where fresh, though commonly breaking down with exposure into thinner-bedded shaly material. It includes also some pale-greenish clayey and sandy strata, beds of mottled green and maroon shale, and harder layers of red or greenish sandstone and limy strata, and in the Montpelier district is defined at the top

[a] Understanding received in personal conference with J. M. Boutwell.

[b] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

and bottom by massive limestones. The limestone or calcareous shale at the top distinguishes the Ankareh from the massive sandstones and red sandy shales of the Nugget sandstone. The limestone at the base of this "red bed" formation is the uppermost of the massive beds that constitute the more prominent part of the Thaynes limestone. The total thickness of the Ankareh as measured in the Montpelier district is about 670 feet, including the limestone at the top but excluding the massive underlying limestone strata more properly classed with the main body of the Thaynes.

NUGGET SANDSTONE.

The Nugget sandstone, overlying the Ankareh shale, is composed chiefly of massive red sandstone, in places much cross-bedded, including also intervals of sandy shale, which are, however, generally obscured at the outcrop by the talus of the more massive strata. In some parts of the area studied beds of pure white and conglomeratic sandstone occur near the base of this formation, and in some areas several hundred feet of white sandstone forms an upper division of the formation. The white sandstone at the top apparently is not found everywhere and where absent may be represented by an unconformity not yet recognized, or the white color may be a local phase of the more common dark-red sandstone. The sandstone is in places vitrified to quartzite. Owing to its massive, resistant character it usually forms high ridges with broad rounding slopes, or in exposure is marked by heavy talus slopes of thick-bedded brown or black weathering sandstone. The thickness of this formation was found to be 1,900 feet in the section measured in Raymond Canyon. Few complete measurements of the formation have been obtained in this general region.

The Nugget is regarded as of either Lower Jurassic or Triassic age, although no fossils have been found in it, its position below the marine Jurassic of the Twin Creek formation and above the beds from which the Triassic ammonoids of Hyatt and Smith are obtained being the basis of this conclusion. It is thought that the formation is in greater part the stratigraphic equivalent of the White Cliff and Vermilion Cliff sandstones of the Uinta and Wasatch mountains, and if so there is some probability that at least the upper part of the Nugget may be Jurassic.

TWIN CREEK LIMESTONE.

The stratigraphic relation of the Twin Creek limestone to the Carboniferous phosphate-bearing strata is more or less remote, but that formation is extensively represented in territory adjacent to the phosphate fields. It is to be noted, however, that phosphate of commercial quality, supposed to have been derived from this formation, was discovered southwest of Cokeville, as described on page 508. As shown by the measured stratigraphic sections, the base of the Twin Creek is separated from the older phosphate by more than 5,000 feet of strata, so that where that formation occupies the surface in normal and unfaulted positions the Carboniferous phosphate is more than 5,000 feet deep.

The Twin Creek limestone consists almost entirely of limestone of more or less muddy appearance when weathered, much of which is thin bedded and shaly, although more massive strata are also included. The characteristic exposures are bluffs or wash banks of splintery fracturing shaly limestone, with white weathered surfaces. The formation contains a number of fossiliferous strata, which determine its age as marine Jurassic. The total thickness of the Twin Creek limestone is probably over 3,500 feet in this area, although no continuous sections sufficiently well exposed to afford satisfactory measurements were encountered during the present work.

BECKWITH AND BEAR RIVER FORMATIONS.

The Beckwith and Bear River formations are extensively developed east of the Sublette Range in Wyoming, and are brought into more or less intimate association with the phosphate-bearing formations by the great fault at Cokeville. Their structural relations in such places render their bearing on the discussion of the occurrence of the phosphate chiefly negative and only the brief descriptions included with the tabular summary on page 469 need be given in this paper.

EOCENE AND LATER DEPOSITS.

Of the later deposits those bearing the most direct relation to the outcrop of the phosphate-bearing strata are (1) the Eocene Wasatch group, as defined by the early geologic surveys, and (2) the more recent detrital and alluvial formations. As all these deposits unconformably overlie the older rocks, they cover and as a rule completely conceal not only the outcrops of the underlying strata but also the structural clues from which estimates as to outcrops or structural relations might be obtained.

Detailed consideration of the Wasatch deposits need not be entered into here, as a number of more or less involved geologic problems must be reviewed in such a discussion. The whole body of early Tertiary sediments is referred to under the general designation, Wasatch, or as Eocene.

The basal part of the Wasatch group in the vicinity of the phosphate fields consists of a coarse bowlder conglomerate (Almy conglomerate of Veatch), in most places dark red, unevenly bedded, and including coarse sandstone and shale, generally more or less loosely consolidated. The bowlder-conglomerate beds are succeeded by finer sediments, including clay shale or marly strata with lenticular sandstones and light-colored chalky limestones, the latter containing many bands of coarsely oolitic limestone which appear to be characteristic of this part of the Eocene (Fowkes formation).

These formations are extensively developed near the Bear River valley east and south of Bear Lake and west of Randolph and Woodruff, where they effectually conceal most of the underlying geologic formations, including the outcrop of the phosphatic rocks. The deposits on Woodruff Creek are revealed by the erosion valley of that stream where it cuts through this Eocene mantle.

The existence and positions of outcrops of phosphate beds underneath the cover of alluvium in the stream valley bottoms or under talus slopes on mountain sides constitute some of the problems to be met by the study of evidence available in areas adjoining the covered region, where the geology of the underlying beds is revealed. Individual areas are discussed more in detail in the following local descriptions.

STRUCTURE.

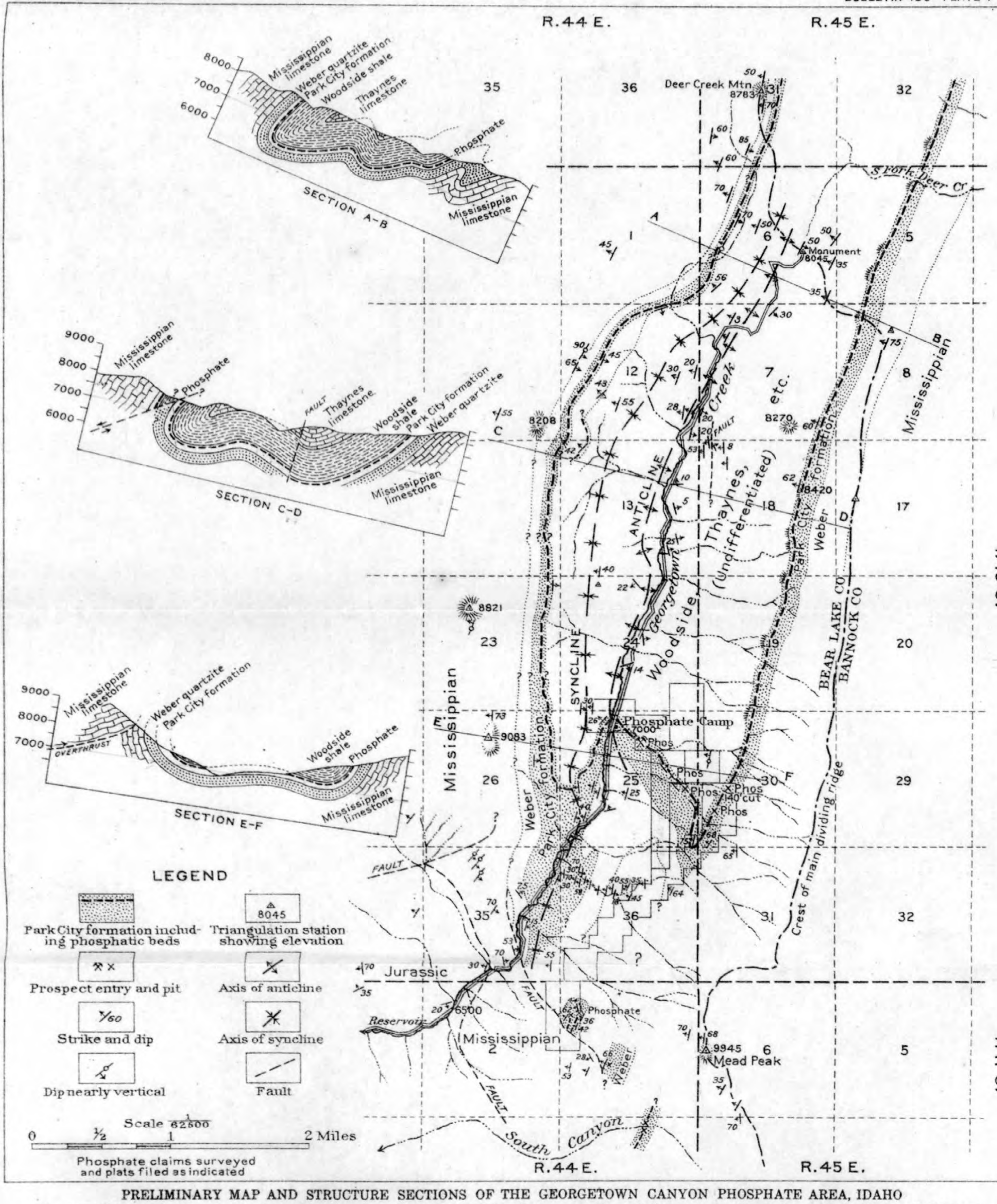
The general geologic structure of this region is that of a closely compressed, overfolded, and overthrust-faulted complex, which is in great part difficult of interpretation. The major structures have a north-south trend, and the direction of the overthrust is universally from the west. The compressive forces have been of such intensity that they have produced many overturned and recumbent folds and overthrust faults, carrying the older hard-rock formations up and over younger strata and contorting and crumpling the beds of the underlying flanks.

Although the complexity is in part rather completely revealed by exposures of Mesozoic and Paleozoic rocks in the more mountainous areas, large expanses of valley lands covered by recent alluvial and detrital deposits and extensive areas masked by Tertiary deposits are probably also characterized by correspondingly complicated rock structure. It is probably altogether unwarranted to assume to predict the attitude or position of beds far beyond the areas from which rather complete evidence is to be had at the surface, and even for such areas the interpretation of some of the evidence is decidedly problematic.

LOCAL DESCRIPTIONS.

AREAS EXAMINED.

The areas examined in detail during the season's work in 1909 are included in the following list. Maps and local descriptions are given in preliminary form in the following pages, together with tonnage and area estimates, based on more or less arbitrary assumptions, as



PRELIMINARY MAP AND STRUCTURE SECTIONS OF THE GEORGETOWN CANYON PHOSPHATE AREA, IDAHO

The township subdivision shown is projected from corners located in the lower valley of Georgetown Creek, beyond the limits of this map explained. The field work of the party was of two types—(*a*) a hasty review, chiefly in the areas in which the evidence is of negative character so far as phosphate is concerned, and (*b*) more detailed surveys and study, including the measurement of outcrops, stratigraphic sections, mapping, sampling, etc. Of the general review little need be said except so far as its results are incorporated in the consideration of the structural and stratigraphic problems of the region and the relation of the areas studied in more detail. The detailed descriptions are arranged for convenience of description, first by the States, and in them roughly according to their location from north to south. The list of areas described is as follows (see fig. 42):

Idaho:
- Georgetown Canyon area.
- Montpelier-Bennington area.
- Hot Springs-Dingle area.

Wyoming:
- Sublette Mountain area.
- Cokeville area.
- Beckwith Hills area.

Utah:
- Crawford Mountain area.
- Laketown area.
- Woodruff Creek area.

This list is by no means complete, not even as to the districts found in the more accessible parts of the region; it comprises only those areas that have been examined.

IDAHO.

GEORGETOWN CANYON AREA.

LOCATION AND DEVELOPMENT.

Phosphate deposits in the upper canyon of Georgetown Creek were among the first to be located soon after the recognition of these deposits as rock phosphate in this western field. This district is directly accessible to Bear River valley and the railroad and the present prospecting is being done in Georgetown Canyon 7 to 10 miles northeast of Georgetown, on the western flank of Mead Peak and the Preuss Range. (See Pl. V.) Phosphate beds extend through Tps. 10 and 11 S., Rs. 44 and 45 E. of the Boise meridian, Idaho, but are also known to be continuous north and northeast of that area, although they have not yet been traced in detail. The canyon of Georgetown Creek forms an elbow, of which the lower half has a general course of S. 70° W. and the upper or northeast half lies in nearly a S. 20° W. direction, evidently derived from or controlled by the geologic structure in that area.

The present study of the Georgetown Canyon district is incomplete; the map presented is tentative in many respects, inasmuch as there are a number of unsolved problems relating to the somewhat complicated structure, and some parts of the mapping on which it is hoped to get further evidence have been omitted. The positions of the

FIGURE 42.—Map showing location of the phosphate areas in Idaho, Wyoming, and Utah.

outcrops of the phosphate beds, shown on the map, are based on locations made from point to point, but the outcrop itself has not been completely traced. It is thought that the representation of the general structure and areal distribution is approximately correct. At the time of the present work in the Georgetown area (September, 1909) development or annual assessment work was being done by the Utah Fertilizer and Chemical Manufacturing Company, which controls all the claims located in this district. Resurveys by the authorized deputy were also in progress and plats have now been filed covering the group of claims shown on this map. The original mineral locations were, however, more extensive, and continued in part as a double strip of placer locations following the outcrop on either side of Georgetown Canyon. These claims appear to have covered most of the actual phosphate outcrop as far as the south fork of Deer Creek on the north and to a point a little beyond South Canyon on the south. As will be pointed out, an extensive area underlain by phosphate at depths presumably nowhere greater than 2,000 feet is included within these outcrops in the upper Georgetown Canyon.

GENERAL GEOLOGY OF THE GEORGETOWN AREA.

The general structure of the upper Georgetown Valley is synclinal, as shown by the structure sections accompanying the map of this area (Pl. V). A structural trough following the main valley is limited on either side by upturned older rocks that form the high ridges bounding the valley on the east and west. The axis of depression is somewhat complicated by minor or subordinate folds parallel to the general structure. As a whole, the character of the folds and of some related overthrust faults is such as to indicate great lateral compression from thrusts originating somewhere to the west and acting toward the east. The synclinal structures rise somewhat toward the south, so that older rocks are exposed in the lower canyon and the phosphate remains only in some more or less isolated patches on the higher ridges. This part of the area is also involved in some rather extensive faults which are in part indicated on the map, but all are not yet thoroughly understood. The undoubted Jurassic and possibly also Cretaceous beds occupy several square miles north and northeast of the power reservoir (including the W. ½ sec. 35, T. 10 S., R. 44 E.), and these beds are distinctly overthrust by Mississippian limestones on the north and are limited by other Mississippian rocks to the east and southeast. The crest of the Preuss Range east of the upper Georgetown Valley is probably of anticlinal structure, and it is thought that one or more correlative synclines, including the phosphate beds, may exist east and northeast of this divide. The structure in the north end of the Georgetown Valley is fairly regular and more readily determined than that farther south. The apparent duplication of outcrops of the cherty limestone associated with the phosphate, noted in sec. 12, T. 10 S., R. 44 E., is not yet understood, but a hypothetical explanation by the assumption of a fault is indicated in the cross section at that place. The apparent relative thinning or absence of part of the Park City formation or Weber quartzite in the northwestern part of the area mapped also requires further study in the field.

The Park City formation, including the phosphatic strata, is apparently typically developed in the Georgetown Canyon area. No single complete section of the whole formation was obtained, but an excellent exposure of that part which includes all the important phosphate-bearing strata was found in a recently opened prospect in the SW. ¼ sec. 30, T. 10 S., R. 45 E., of the theoretical subdivision as shown on the map (Pl. IV). This section has already been described in considerable detail (p. 477), which need not be repeated here. The cherty limestone overlying the phosphatic strata forms a prominent ledge outcropping at intervals throughout the area and is the principal marker by which the phosphate beds are traced. The limestone underlying the phosphatic beds is composed of massive bedded rocks, containing much black chert in nodular form, in this respect resembling the succession at Montpelier Canyon.

The Weber quartzite, underlying the Park City formation, is well exposed in the main canyon in sec. 25, T. 10 S., R. 44 E., where it shows chiefly as a talus of white, somewhat calcareous, and in places brownish or yellowish weathered quartzite or sandstone.

The Mississippian limestones normally underlying the Weber occupy the dividing ridges both east and west of the upper Georgetown Canyon and are also thrust in by faults at the south end of this phosphate area. A single collection of fossils obtained near the summit of the ridge south of Preuss Peak appears to represent an upper Mississippian fauna. No lithologic distinction between the upper Mississippian and the Madison or lower Mississippian portion of the series was recognized. The Mississippian rocks consist chiefly of massive dark-bluish or black weathering limestone, commonly showing well-preserved corals on the weathered surfaces. The summit of Mead Peak affords an excellent example of the massive dark-bluish fossiliferous limestone of this part of the section.

Of the strata overlying the Park City formation, the Woodside shale, next succeeding, and the Thaynes limestone are most important as furnishing evidence of the depth of the phosphate beds along the axes or within the synclines. The Woodside shale is composed of reddish and brownish weathering shales and some limestones, including one or more characteristic fossil horizons. This formation is also represented in the thin-bedded micaceous shales and fine-grained sandstones of gray, greenish, and brownish casts, outcropping in many of the road cuts north of the phosphate camp. An arbitrary upper limit of the Woodside shale has been assumed to be that marked by the so-called *Meekoceras* zone, which is therefore regarded as the base of the Thaynes. The thickness of the Woodside is about 1,000 to 1,200 feet in this area, and as the outcrop of that formation occupies most of the lands along the channel of upper Georgetown Creek, it thus gives an approximate indication of the depth to the phosphate beds. An excellent example of the "*Meekoceras* limestone" is to be found in the road gap on the divide between this canyon and the south fork of Deer Creek, where it is marked by a rock monument, erected for triangulation. Numerous well-preserved specimens of the "ammonites" or cephalopods from which this zone is named have been obtained here and also at other points lower in Georgetown Canyon. The fauna occurs at several different horizons within the *Meekoceras* zone, which here aggregates 200 to 300 feet in thickness.

As in the Montpelier district, the main phosphate bed in Georgetown Canyon occurs at the base of the phosphate section. It varies in thickness but appears to average somewhat over 6 feet in the places where it has been opened so that its total thickness can be determined. The rock phosphate is of high grade, as shown by the tests, of medium to coarse oolitic texture, and of dark grayish-brown color, almost black when fresh, and contains but little foreign matter in the form of partings. It is capped by a single 2-foot stratum of dark fine-grained fossiliferous limestone, as at the Montpelier properties. As may be seen from the section described on page 23, nearly all these strata appear to be rather highly phosphatic, including several high-grade beds above the principal one occurring at the base. In considering this section as representative, however, it seems best to bear in mind that the exposures from which these samples were taken were near the surface of the ground, the strata standing in nearly vertical position, and all were more or less weathered and of earthy composition, a factor which is generally understood to enrich the phosphatic content. (See p. 468.) Enrichment may have been due in part to a secondary replacement of lime by phosphoric acid, but in most weathered exposures it seems to be largely the result of leaching of the more readily soluble lime, the proportion of the residual phosphates being thereby increased.

The lower phosphate bed has sometimes been locally referred to as the "black phosphate" and an upper prospected bed as the "gray phosphate." There is probably no essential difference in the character of the various high-grade beds of this section, although some are not so dark colored as others and some are more coarsely oolitic. The massive, coarsely oolitic material is generally considered the best. The dark color is believed to be due to carbonaceous matter, extraneous to the phosphatic minerals or substance, and not an indication of the richness of the beds.

The lower main phosphate bed was sampled at the breast of the tunnel on the Highland placer claim (NW. ¼ sec. 1, T. 11 S., R. 44 E.), representing 6 feet of apparently fresh, unaltered rock. The tunnel runs in about 60 feet S. 70° W. and then turns southward, following the bedding or strike for about 30 feet more, and appears to have been one of the principal developments on the claims originally staked in this area. Analysis of this specimen shows 35.7 per cent of phosphoric acid (P_2O_5), equivalent to 78.2 per cent of bone phosphate ($Ca_3(PO_4)_2$). Another sample from the lower or main bed in a shallow trench in the NE. ¼ SE. ¼ sec. 25, T. 10 S., R. 44 E., representing a thickness of 6 feet 6 inches, gave 37 per cent of phosphoric acid (P_2O_5), equivalent to 81 per cent of bone phosphate ($Ca_3(PO_4)_2$). This was an average sample of massive though somewhat weathered material.

The series of tests recorded in the table on page 477 has already been discussed, and completes the analytical work done for this locality.

AREA AND TONNAGE.

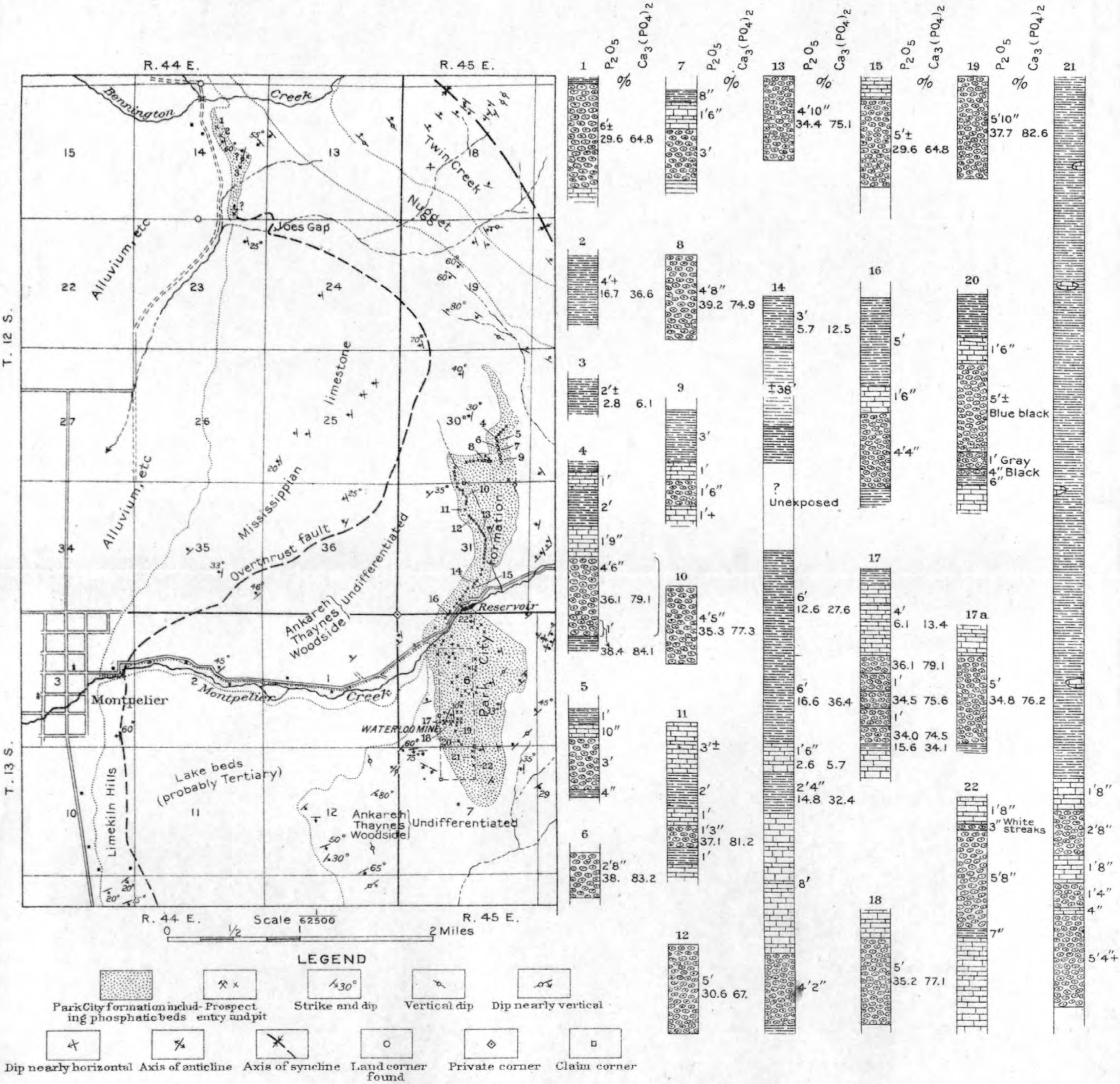
An estimate of the area of the lands underlain by phosphate in this district, including only those lying in the drainage basin of Georgetown Creek, based on the outline shown on the accompanying map (Pl. V), gives 3,840 acres, or 6 square miles. As stated, all of this phosphate may be considered as ultimately available, as the greatest depth from favorable entry points is perhaps not more than 2,000 feet. As shown by the structure sections on the accompanying map (Pl. V), the surface area of the phosphate bed itself is considerably in excess of the areal measurement of the land under which it lies, owing to the fact that the strata are compressed in folds and a vertical element must also be considered in reckoning the volume. The assumption that a single 6-foot bed of phosphate extends under this area, with an extra allowance of 15 per cent for the vertical element in the structural position of the beds, gives somewhat more than 90,000,000 tons of 2,240 pounds from the main bed alone of the best-grade phosphate rock for the area in the drainage basin of Georgetown Creek. The complete section doubtless contains several times this amount of high-grade rock and a much greater mass of low-grade material, but more accurate estimates of the total amount of phosphatic rock available are perhaps not worth while from the present evidence.

MONTPELIER-BENNINGTON PHOSPHATE AREA.

LOCATION.

The phosphate deposits in Montpelier Canyon, Idaho, have long been a subject of interest to prospectors and others, and the outcrops of these black rocks had been dug into and tested for coal and mineral values long before their phosphatic content was discovered. The same may also be said of the Bennington outcrops, but when the phosphate itself was recognized, the Montpelier deposits, on account of their proximity to the railroad, appeared to offer exceptional inducements to early commercial development.

The outcrops in Montpelier Canyon lie in a strip extending from north to south through secs. 30 and 31, T. 12 S., R. 45 E., and secs. 6 and 7, T. 13 S., R. 45 E., of the Boise meridian. (See Pl. VI.) The outcrops are visible from points in the town of Montpelier, showing as a black streak traced across the hillsides. The main



MAP OF THE MONTPELIER-BENNINGTON PHOSPHATE AREA, IDAHO, WITH SECTIONS AND ANALYSES OF PHOSPHATE BEDS developments are about due east of Montpelier, and the Waterloo mine is 4½ miles, by wagon road, from the railroad station.

The outcrop of the phosphate rocks is largely covered by mining-claim locations. These claims were originally staked as placers and one of them has been admitted to final proof, the title having been granted to the San Francisco Chemical Company. This firm owns a plant at Martinez, Cal., 37 miles from San Francisco, and is engaged in the manufacture of superphosphates. The company also holds nine other claims in the Montpelier area, three claims on Thomas Fork in the Sublette Mountains, Wyoming, three claims at Swan Lake, north of Georgetown, Idaho, and five claims on Woodruff Creek, Utah. Most of these claims have later been relocated under the lode law, a condition resulting from the inadequacy of the present mining law as applied to the phosphate lands. (See pp. 532–535.)

The Bennington prospects are situated in sec. 14, T. 12 S., R. 44 E., and the deposits on which they are located doubtless form a direct extension of the beds in Montpelier Canyon, although the outcrop of the phosphate itself is concealed for an interval of 2½ miles, a condition to be explained from the geologic structure of the region.

GENERAL GEOLOGY.

The phosphate deposits of the Montpelier Canyon area outcrop at the crest of a closely compressed, overturned, and somewhat faulted anticline. The general geologic structure of a considerable area in that vicinity is directly incident to this controlling structural feature. The trend of the anticlinal axis is in the main north and south, with a bend toward the west at its north end. The overturning is evidently due to thrusts that have acted from the west toward the east, and the same general tendency is exhibited in even the more minute structural details of the whole area. Minor fractures of overthrust character occur within the phosphate or associated rocks, showing a displacement by minor crumpling and shearing, in which the direction of thrust has evidently been toward the east; thus the strata on the west of the anticline tend to ride up and over, and those on the east show a corresponding compression and internal contortion, as they have borne the weight of the overturned structure. The magnitude of this upheaval is in part shown by the fact that the entire stratigraphic section from the Park City formation up to and including the Twin Creek limestone—a series at least 8,000 feet in thickness—now lies in inverted order on the east side of this axis, with moderate westward dips as if in simple folded structure.

The western overthrust flank of the major anticline is somewhat less disturbed than the underlying flank and the younger formations overlie the older in normal succession; thus the section in the lower Montpelier Canyon, west of the phosphate mine, is relatively simple and affords a fairly good opportunity for detailed study of the overlying Woodside and Thaynes formations. At the extreme lower or west end of the canyon the section is truncated by an overthrust of the Mississippian limestones. Irregularity in structure in this part of the field is shown by the scattering dips and strikes recorded on the map (Pl. V), the entire significance of which has not yet been satisfactorily worked out.

The detailed stratigraphic section of the beds overlying the phosphate in Montpelier Canyon has been reviewed in considerable detail under the heading "Stratigraphy" (pp. 472–473). The Park City formation, which contains the phosphate beds, is apparently typically developed. An upper cherty limestone member containing *Productus* of several species, including *P. semireticulatus* and less commonly other species as distinguishing fossils, overlies about 200 feet of the dark-brown and black phosphatic shales, with which are associated some limestones. The lower part of the Park City formation consists of cherty limestone and shale, probably in large part calcareous. The total thickness can not be determined with certainty in this area on account of the many minor structural irregularities in the exposures of these rocks, but it has been estimated to be about 600 feet or possibly somewhat more.

The formation normally succeeding the Park City is the Woodside shale. A description of these beds is included in the detailed section on page 473; they consist mainly of calcareous shale or shaly limestone, characteristically weathering to a brown or rusty color with sandy or muddy surfaces, including an interval of distinctly red shale in the upper part. A somewhat arbitrary upper limit to the Woodside shale has been adopted, as defined by the *Meekoceras* zone as the base of the more massive limestone sequence which is included with the overlying Thaynes. The thickness of the Woodside shale below the *Meekoceras* zone is about 1,000 feet, or possibly a little more.

The Thaynes limestone consists largely of muddy-brown weathered limestones and calcareous shale, in places very fossiliferous. In many of the more massive strata the rock appears to be made up of a mass of fragmentary shells which show by differential weathering, but the same rock, when freshly broken, appears to be a dense, compact, apparently structureless limestone. The weathered rock commonly looks like rusty sandstone but proves to be a dark-bluish limestone when broken.

The Ankareh, Nugget, and Twin Creek formations are also typically developed, but appear only on the east side of the overturned anticlinal axis in this area. They are, however, in inverted order, and so have only more or less indirect significance as to the depth of the phosphate beds.

Rocks older than the Park City formation are not exposed in the crest of the anticline that brings up the phosphate. The Mississippian limestones are overthrust along the west face of the Preuss Range from Joes Gap to the Limekiln Hills east and southeast of Montpelier. They are shown on the geologic map (Pl. VI) as limited by the fault on the east and disappearing under the alluvium-filled valley on the west.

PROSPECTS AND DEVELOPMENT.

WATERLOO CLAIM.

The principal developments in the Montpelier area are on the Waterloo claim in Montpelier Canyon. The phosphate of this claim is situated on a broad, rather smooth, rounded dip slope at the west foot of Waterloo Mountain. The hillsides are traversed by shallow gullies which cut the main phosphate bed in many places. The actual outcrop of the main bed is somewhat difficult to trace with certainty, as the hillsides are grassy and only the harder limestone ledges are naturally exposed. The upper beds of the phosphatic section have been largely removed by erosion from the higher hill slopes, but as these beds dip to the west the whole section may be expected near or below water level. A considerable amount of rock phosphate has been shipped from this place, and the whole property has been rather extensively prospected. The main workings are near the center of the claim, which is of the association placer type (160 acres), an area 1 mile long from north to south and one-fourth mile in width, including the SE. ¼ NW. ¼ and the E. ½ SW. ¼ sec. 6 and the NE. ¼ NW. ¼ sec. 7, T. 13 S., R. 45 E. Near the center of this claim an open cut has been quarried covering an area some 200 feet square, exposing the bare ledges of the limestone underlying the main phosphate bed on the western dip slope of the hill. These rocks dip 30° to 32° W. Two mining tunnels have been run in below the open cut. Both are under shallow cover, the upper one starting directly from the outcrop and the lower one crosscutting but a short distance into the same bed. A shaft has been sunk near the mines just west of the Waterloo claim, but had not been completed at the time the property was visited.

A number of tests and measurements of the main phosphate bed in the Montpelier area were made in the present work, and the results are shown in a graphic way in connection with the map of the district (Pl. V). As indicated in the following section, the principal phosphate bed occurs at the base of the phosphate-bearing sequence and is everywhere overlain by a fossiliferous stratum of dark, fine-grained limestone. The phosphate itself is black, of a shaly or thin-bedded structure, much resembling coal in general appearance, especially in a natural exposure or weathered outcrop, but lacking the pitchy luster of coal. Wherever it lies within 30 or 40 feet of the surface, the main phosphate bed has proved sufficiently soft to be mined with a pick, the entries being advanced with a breast auger drill as in coal mining. The detailed measurements obtained at the mouth of the upper tunnel on the Waterloo claim were as follows:

Section at Waterloo claim, Montpelier Canyon, Idaho.

	Ft.	in.
Shale	10+	
Limestone, black, fossiliferous	1	6
Shale, gray to brown, phosphatic (?)	2	6
Limestone (cap rock), very fossiliferous (P_2O_5, 6.1 per cent)	1	10
Phosphate, main bed (P_2O_5, 38 per cent)	5	6
Shale, brown to black	1—	
Limestone, black, massive strata, underlying the phosphate-bearing section (not measured).		
	22	4

The beds on the Waterloo claim dip westward at angles ranging from 17° to 42°, showing also considerable irregularity of strike, even within the limits of the claim. In the large open cut above the upper tunnel there are small displacements or faults of a type that is apparently significant of the character of the larger structures of the whole general region. Slivered fractures in the "cap lime" pass into folds and crumpled zones in the phosphate itself, thickening and thinning the latter bed.

The beds on the Waterloo claim are very conveniently situated for ready accessibility and economical mining, perhaps as much so as in any other part of the area that has been studied. Probably the greater part of this claim is underlain by the main phosphate bed, so that an estimate of tonnage is a comparatively simple matter. Estimating the main bed as 5 feet 6 inches thick under an area of 140 acres gives in round numbers 2,500,000 tons of 2,240 pounds for this single claim. These figures make no allowance for recovery in mining. All of this rock lies above main drainage level and at comparatively shallow depth, so that it is probably readily accessible for mining. Although it is possible that a truly conservative estimate of the tonnage on this claim should be reduced somewhat from the figures just given, to allow for possible irregularity in structure or for crushing and thinning of the workable beds, yet on the other hand these factors are to a certain extent counterbalanced by the probable existence of other workable beds that are usually found in the more complete section and thus may be assumed to be present at the lower or western limits of the Waterloo claim. The more readily available material lying above drainage level will probably be mined before any extensive developments are made reaching below water level.

NORTHWARD EXTENSION OF PHOSPHATE.

Other claims situated both east and west of the principal phosphate outcrop, but chiefly on its extension to the north, have been located in the Montpelier Canyon area. On these the more complete section of the phosphate beds, 150 to 200 feet thick, is represented here and there. Numerous sections, chiefly of the main bed, were examined in the prospects, many of which had caved so badly since the opening was made that they did not afford much evidence of the actual condition of the beds. Phosphatic strata range through an interval of 150 to 200 feet, but as they are composed essentially of soft and readily eroded material they are almost universally covered by soil or talus from harder rock ledges and fresh exposures are to be had only where recent prospecting has opened them.

A partial section of the phosphatic shales was measured and sampled in a horizontal trench cut across the steeply dipping beds on a spur northwest of the Montpelier waterworks dam, and is given in the following table:

Section of phosphatic beds in Montpelier Canyon, Idaho.

	Ft.	in.
Shale, soft, phosphatic (sampled 2 to 3 feet in the upper part); top not reached	40	
Limestone stratum, brecciated; weathers to an earthy or muddy color	2	6
Shale, soft, black, mixed with earth (P_2O_5, 12 per cent)	2	
Shale, including soft, thick limestone nodules	3	
Shale, black; appears somewhat phosphatic	2	
Shale, black, containing one large limestone nodule (not included in sample) (P_2O_5, 12.6 per cent)	6	
Limestone, cross section of nodule interbedded in black shale; measured at its thickest part		8
Shale, black, claylike; shows little or no sign of oolitic structure (P_2O_5, 16.6 per cent)	5	
Limestone, hard, dark colored, similar to nodules that occur in the overlying shale; appears phosphatic at top (P_2O_5, 2.6 per cent)	1	5
Shale, black, probably phosphatic (P_2O_5, 14.8 per cent)	2	4
Limestone, somewhat fossiliferous; forms the roof of the main phosphate bed	2	
Phosphate, main bed not measured at this place, approximate thickness	5	
	72	5

Extensive, almost continuous prospecting along the outcrop northward from the waterworks dam has traced the main bed in Phosphate Gulch and across a dividing spur to the west side of Home Canyon, in the eastern part of sec. 30. At this locality the outcrop disappears and it was not found again nearer than the exposures to the south of the lower end of Bennington Canyon, at the western foot of the Preuss

Mountains. Prospects revealing the phosphate are, however, reported in line with the anticlinal axis near the divide between Home Canyon and Joes Gap. It is thought that this disappearance of the outcrop of phosphate beds is to be explained by the pitching of the axis of the anticline along which the phosphate has been brought up, so that although the deposits themselves are probably continuous, the outcrop is lost for intervals across the intervening high land. Much irregularity is to be observed in following the outcrop in and beyond Phosphate Gulch, where local slips and faults offset the beds in many places. The sections measured, together with the results of chemical tests, are shown in graphic form on the diagram accompanying the map (Pl. VI).

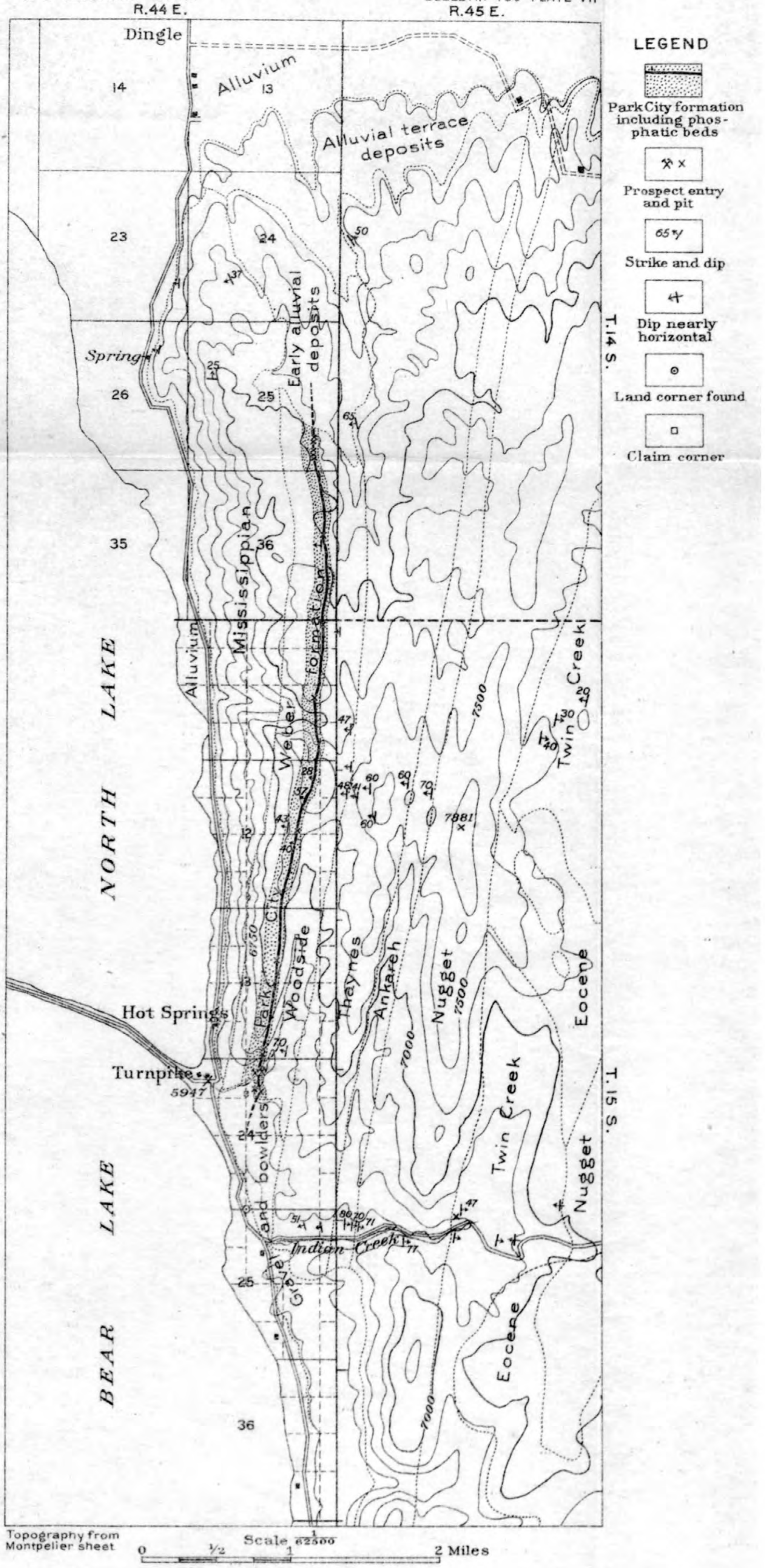
SOUTHWARD EXTENSION OF PHOSPHATE.

In the immediate vicinity of the Montpelier area the phosphate has not been traced by outcrops south of the Waterloo claim. Although the structure is far from simple, the evidence apparently indicates that the anticline by which these outcrops are brought up pitches toward the south. The southern extension of the workable deposits is lost in the low grass-covered slopes southeast of Waterloo Mountain. By inference from structures observed in the harder rock strata associated with the phosphate beds, the concealed outcrop is assumed to nose around the end of this pitching anticline, as represented on the map. Outcrops of limestones both overlying and underlying the phosphate beds have been observed in the E. ½ sec. 6, presumably forming a part of the east flank of the anticline already described. All the strata on the eastern flank of the major anticline are, however, considerably contorted, and it seems likely that the outcrop of the phosphate beds on the east flank is to a large extent cut out by more or less extensive overthrusting near the axis of the overturned anticline. This explanation has been assumed to account for a failure to discover a second outcrop in Montpelier Canyon east of the waterworks dam or in Phosphate Gulch.

The phosphate beds occurring on the underlying side of the overturned anticline doubtless pass to great depths, perhaps 10,000 feet or more, as the inverted section may be assumed to double over the axis of the recumbent syncline. For this reason it is extremely doubtful if much of the territory east of the major anticlinal axis can ever be considered valuable for the phosphate that probably underlies it.

BENNINGTON OUTCROPS.

Outcrops of the phosphate and the overlying cherty limestone near Bennington Canyon have already been mentioned (p. 493). As explained, they are thought to be brought up by the same structural fold by which the Montpelier phosphate beds are revealed. An inter-



GENERAL GEOLOGIC MAP OF HOT SPRINGS-DINGLE AREA, IDAHO
showing extent of known phosphate outcrops

val of about 2½ miles between the outcrop in Phosphate Gulch and Home Canyon and those near Bennington is covered by younger beds, evidently arched over the axis of the anticline referred to, which may be traced through the divide separating the drainage of Joes Gap from Home Canyon. This structure is in part obscured to the west, near the summit of the ridge, by the overthrust body of Mississippian limestone of which the Joes Gap cliffs are a part.

AREA AND TONNAGE.

An estimate of the available phosphate on the Waterloo claim has already been given, in which the total of 2,500,000 long tons is based on a single 5½-foot bed of the best-grade material. Complete and reliable estimates covering the whole area in the vicinity of Montpelier Canyon are practically impossible, owing in part to the uncertainty arising from the irregularity of the geologic structure. Only the most general estimates can be made, as, for instance, those based on an assumption of the existence of a 5-foot bed of phosphate rock available to a depth of about 2,000 feet, or for a distance of half a mile from the outcrop on the more gently dipping beds. The total length of the outcrop as known at present is about 15,000 feet, in which is considered only those beds on the west flank of the major anticline. On the assumptions stated, this would give a total of approximately 16,000,000 long tons in the Montpelier area. The standards given are, of course, exceedingly arbitrary, but are in a general way comparable to those used in the other estimates made in this report. Any attempt to take into account other beds of either the best or the low-grade phosphatic material introduces into the computation so many additional factors of uncertainty, which would have to be reckoned through merest assumption, and runs up the figures to such an almost incomprehensible quantity that the simplest form of statement will perhaps serve best for purposes of comparison.

HOT SPRINGS-DINGLE PHOSPHATE AREA.

GENERAL LOCATION.

Phosphate beds extend in a belt of continuous outcrop about 4½ miles long from the vicinity of Hot Springs, at the northeast corner of Bear Lake, to the valley flats south of Dingle, Idaho. (See Pl. VII.) The nearest shipping point is Dingle, on the Oregon Short Line Railroad, which is about 10 miles from the south end of this belt, near Hot Springs. The outcrop of the phosphate itself is characteristically somewhat obscured, as the soft, shaly beds readily break down on exposure and are concealed by soil and slide, but its position is distinctly indicated by the prominent ledges of the associated cherty bed that forms a most conspicuous and easily recognizable marker and occurs throughout this area to the east of the phosphate.

GEOLOGY.

Like the deposits in the Sublette Mountains, Wyoming, those at Woodruff Creek, Utah, and those near Paris and Bloomington, Idaho, the Hot Springs phosphate beds are exposed in an extensively overturned stratigraphic section. These beds presumably represent the underlying eastern flank of an anticline which has been overturned toward the east and from which the upper or western flank has been completely removed by erosion or perhaps displaced by faulting. In spite of the magnitude of the major overturn, the structure is comparatively regular in minor detail and little evidence of distortion or crushing was observed in the softer beds. Some transverse offsets are shown in the massive cherty ledges associated with the phosphate beds, an instance being noted in the channel of the dry wash on which the Hot Springs prospects are located.

Although the strata dip toward the west at the outcrops, it is evident from the structure that these beds must turn back to an easterly dip in depth, so that they pass in normal position through the series of folds observed between Hot Springs and the Wyoming state line. The stratigraphic section at Hot Springs is apparently very much like those of the Sublette Mountains and other places in this general region.

PHOSPHATE BEDS.

The outcrop of the phosphate strata is readily identified and traced by means of the excellent exposures of the black chert ledge which forms so conspicuous a marker in this area. The phosphate itself has been prospected to a small extent, but at none of the openings that have been made was there revealed a satisfactory section of all the phosphatic beds. It appears, however, that the series is much like that at Montpelier and doubtless contains similar workable beds, as well as a considerable amount of lower-grade rock, not at present considered commercially valuable.

The principal developments consist of a double set of entry tunnels opening the phosphate at the same place and located in a small gulch about half a mile east of Turnpike post-office, at Hot Springs. These entries are situated in the NW. ¼ NE. ¼ sec. 24, T. 15 S., R. 44 E. The duplication of work at the discovery tunnels is the result of conflict among claimants to the property. The following is a complete section, together with the analytical tests made, of the beds exposed underground in the crosscut joining the entry tunnels; it was made at the time of examination of this property (September, 1909):

Section of phosphate and associated beds at Hot Springs, Idaho.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
	Limestone, compact, hard	....	....	10+	
141-A	Shale, brown, earthy, calcareous	9.0	19.7	1	6
141-B	Shale, earthy, massive	2.0	4.4	2	8
141-C	Phosphate, oolitic, massive, dark gray	32.8	71.8	2	2
	Limestone, massive stratum	....	....	2	2
111-D	Phosphate, medium to coarsely oolitic, dark gray	32.3	70.7		11
141-E	Shale, brownish, earthy, calcareous	3.5	7.7	1	
141-F	Phosphate, medium grained, oolitic, dark gray	36.3	79.5	1	3
141-G	Phosphate: (*a*) Shale, calcareous ... *In.* 5; (*b*) Phosphate, oolitic, brownish ... 4; (*c*) Shale, brownish, phosphatic ... 2; (*d*) Shale, brownish, phosphatic ... 11	27.5	60.2	1	10
141-H	Phosphate, medium to coarse grained, oolitic (main entry tunnel)	29.1	63.7	5	10
141-I	Phosphate, medium to coarse grained, including pebbly texture	28.0	61.3	1	5
141-K	Shale, phosphatic, dark brown, earthy	24.3	53.2	11	
	Limestone	....	....	1	
141-L	Shale, phosphate, dark brown, earthy	12.9	28.3+	10	6
	Shale, phosphate, dark brown, earthy	....	....	4	11
141-M	Shale, phosphatic, somewhat oolitic	20.3	44.5	1	8
141-N	Shale, phosphatic, dark brown, earthy	5.2	11.4	4	6
				64	4

A section of a workable bed recently opened in a prospect tunnel 600 feet S. 15° W. of the main entries described above exposes material of apparently higher grade than any included in the preceding section. The correlation of this bed with any particular part of that section can not now be positively made, but it seems likely that the 63 feet of strata exposed in the crosscut of the main entry described above do not include all of the best material that may be present in that section.

Section from prospect near Hot Springs, Idaho.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
137-A	Phosphate, coarsely oolitic, dark gray	36.2	79.3	1 3
137-B	....do	24.7	54.1	5
137-C	....do	34.8	76.2	1 8
137-D	....do	37.0	81.0	1 8
	Average	35.0	76.5	[a] 5

[a] Total.

AREA AND TONNAGE.

Calculations based on assumptions similar to those used in the other areas for estimates of the tonnage of valuable rock phosphate are given as follows:

The known outcrop of the phosphate beds is 23,500 feet in linear extent, beyond which, both to the north and south, these rocks are doubtless continuous and readily accessible for a distance of 10,000 feet or more (1½ miles on the north and half a mile toward the lake on the south), where bed rock is assumed to be under relatively shallow cover. Thus the estimates are based on a total length of 33,500 feet. The strata dip to the west at angles averaging from 40° to 60° and an ultimate depth along the bed of 2,000 feet has been assumed as the limit of the rock that need be considered immediately available in mining. Taking into consideration but a single 5-foot bed of higher-grade ore (equivalent to 70 per cent or more of tricalcium phosphate) and assuming that such a bed may be found in some part of the section throughout the field, we obtain in round numbers 27,000,000 long tons of phosphate for the Hot Springs area.

A strip of 40-acre tracts adjoining the phosphate outcrop, arranged so as to include the surface overlying the bed wherever it is not more than 2,000 feet in depth, covers an area of approximately 1,300 acres, or about 2 square miles.

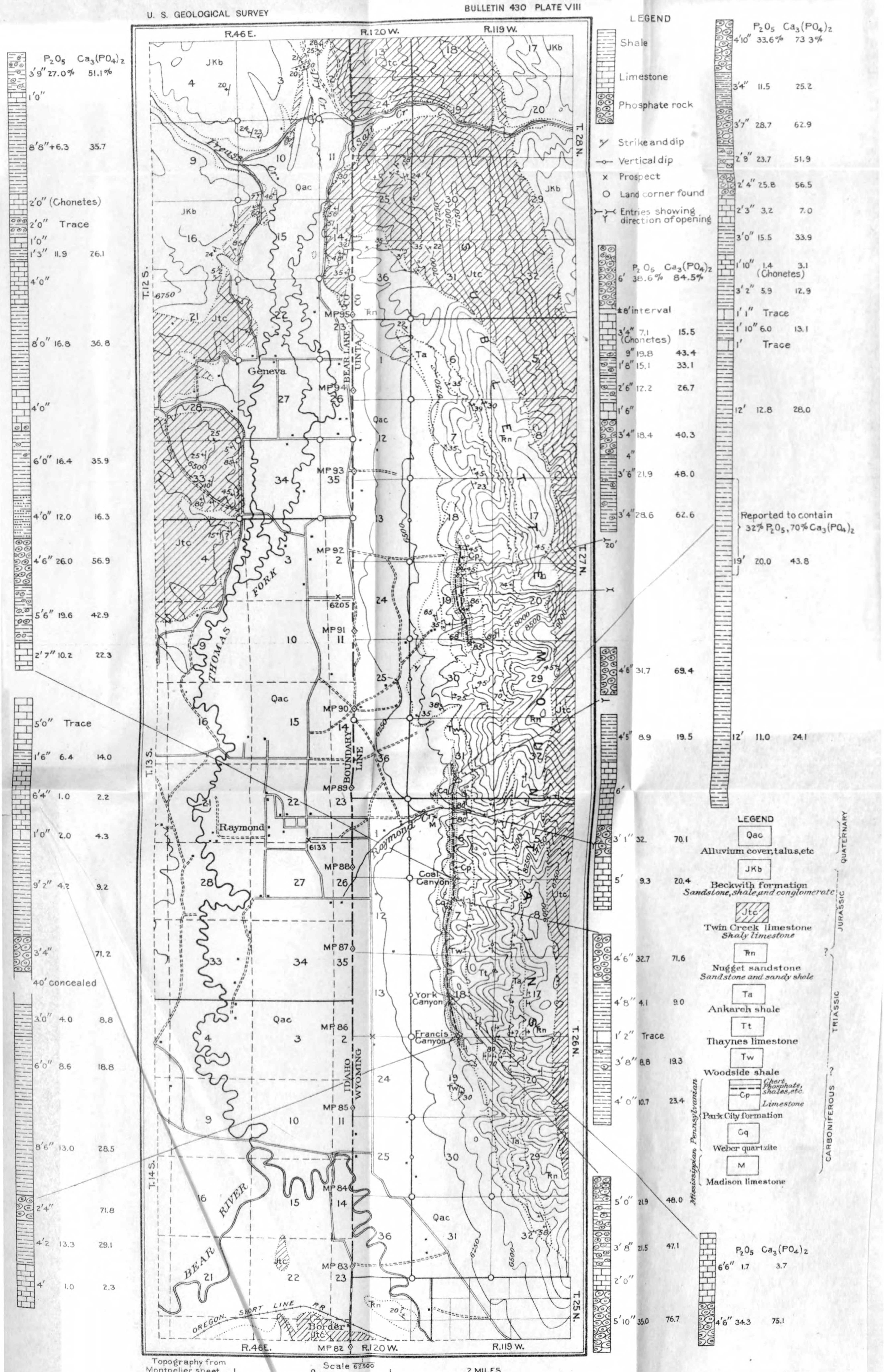
WYOMING.

SUBLETTE MOUNTAIN PHOSPHATE AREA.

LOCATION, ACCESSIBILITY, ETC.

The Sublette Range as approached from the west is a somewhat isolated mountain mass, rising abruptly from the flat valleys of Thomas Fork and Bear River just east of the Idaho-Wyoming state line. The maximum relief between Bear River and the highest summit is 3,250 feet. The range is terminated at the north by the Salt Creek branch of Thomas Fork. Southward it extends as a high rugged ridge for about 15 miles, beyond which it is continued 8 miles in lower, more or less disconnected peaks and ridges, ending in the two rocky hills just east of Cokeville. The main range is cut transversely by the deep, narrow canyon of Raymond Creek, and the lower ridge at the southern end of the range is also cut through to water level by the valley of Birch Creek, a short distance northeast of Cokeville.

The principal phosphate area of the Sublette Mountains lies along its western foothills, just above the slide-rock and valley fill at the margin of the Thomas Fork valley. (See Pl. VIII.) Outcrops of the phosphate beds have been located about 3 miles north of the canyon mouth of Raymond Creek and in almost continuous outcrop an equal distance south. All these beds are readily accessible from Thomas Fork and are within easy access of the Oregon Short Line in Bear River valley. This railroad at Border station is about 6 miles due south of Raymond post-office.



GEOLOGIC MAP OF SUBLETTE MOUNTAINS, WYOMING, AND ADJACENT PORTIONS OF IDAHO
showing extent of known phosphate outcrops, with sections and analyses of phosphate beds

GEOLOGY OF THE SUBLETTE MOUNTAINS.

STRUCTURE.

The Sublette Mountains evidently represent a closely compressed anticline, of which the western flank is in greater part either cut away by the erosion, or has been thrown down by faulting on the Thomas Fork side. The anticlinal axis lies along the west foot of the range, and the phosphate is brought up in the crest of the anticline. The main range consists of the steeply dipping strata on the eastern flank of the anticline, lying apparently in normal succession; the eastern slopes of the mountains are composed of the later Jurassic and possibly Cretaceous rocks, involved in subordinate folds of closely compressed structure that are evidently related to the major axial fold.

The major anticline plunges toward the north and the structure is well brought out in the distribution and attitude of the rocks exposed in that part of the area. On the west and to the south, however, the alluvium-filled valleys conceal nearly all evidence of the structural relations and the geology of the underlying rocks is to be understood only in a general way by inference from scattered exposures.

The exposures of phosphate beds near Cokeville are brought up along a subordinate anticlinal axis east of the main anticline of the Sublette Range. The beds in the Cokeville area are commercially and structurally distinct from the deposits on the west side of the Sublette Mountains in the Thomas Fork valley. (See Pl. IX.)

STRATIGRAPHY.

The general stratigraphic section in the Raymond Creek canyon has been described on page 471. The Park City, Woodside, Thaynes, Ankareh, Nugget, and Twin Creek formations are apparently here typically developed. The Weber quartzite underlying the Park City includes some massive, sugary white calcareous strata which were not distinctly differentiated from the lower limestones of the Park City formation or from the uppermost Mississippian limestone at the time this work was done, but it is thought that both in the Sublette Range proper and in the hills east of Cokeville the Weber is either thinner or less characteristically quartzitic than at most other parts of the field.

The summit of the Sublette Range south of Raymond Canyon is covered with a deposit of gravel and water-rounded bowlders, concealing the outcrops of underlying rock. For the most part these materials appear to be but slightly agglomerated at the surface, exceptions, however, being noted in the wash bluffs on the east side of the summit. This deposit is probably a remnant of the Eocene conglomerate (lower Wasatch), which is found in much more extensive development at lower elevations, but which is here elevated to approximately 9,000 feet above sea level. Later movements in this range have, therefore, taken place in Eocene or post-Eocene time, if the assumption of Wasatch age of the conglomerate is correct.

PHOSPHATE DEPOSITS.

T. 27 N., R. 119 W., WYOMING.

The northernmost exposure of the phosphate-bearing portion of the Park City formation consists of a closed outcrop in secs. 18, 19, and 30, T. 27 N., R. 19 W., circling around the northward-plunging anticlinal axis. This particular outcrop is significant in that it gives a definite clue to the major structure of the Sublette Range, which is obscured toward the south by the cover of alluvium and talus. In section 30 the Woodside shale and a portion of the Thaynes limestone form an uneroded arch, which covers the Park City beds for a distance of about a mile. In the same section erosion has been effective in uncovering the eastern outcrop of the Park City formation and its inclosed phosphatic portion. The deposits of alluvium, however, have concealed the position of the nose of the southern outcrop of the anticline and the outcrop of the phosphate beds on the western flank of the fold. The best (though incomplete) section of the phosphate beds, measured on the northern outcrop, is as follows:

Section of phosphatic beds in sec. 19, T. 27 N., R. 119 W., Wyoming.

Field No. of specimen.		P_2O_5	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
44	Phosphate rock, grayish black, oolitic	38.6	84.5	6	
	Interval, concealed			8+	
43-A	Limestone, grayish black, hard; fossils	7.1	15.5	3	4
43-B	Shale, black, in part oolitic, soft	19.8	43.4		9
43-C	Shale, black, in part oolitic	15.1	33.1	1	8
43-D	Shale, black, in part oolitic, massive	12.2	26.7	2	6
	Limestone			1	6
43-E	Phosphatic rock, black, coarsely oolitic, soft	18.4	40.3	3	4
	Limestone				4
43-F	Shale, black, soft, oolitic	21.9	48.0	3	6
43-G	Shale, brownish black, oolitic	28.6	62.6	3	4

The cross section of the anticlinal axis is well exposed in the gulch in which the above section was measured. Immediately underlying the portion of the section given in detail is a series of dark-colored shales containing limestone lenses which indicate the total thickness of the phosphatic portion of the Park City formation as somewhat less than 100 feet at this place. The sandy limestones of the basal part of the Park City formation and the overlying cherty beds make prominent cliffs directly above and east of the prospects.

In the southeast corner of sec. 31 there are several prospects, but the best section is exposed in the tunnel opened by the San Francisco

Chemical Company. The direction of the tunnel is nearly northeast and southwest and it cuts the approximately vertical beds at right angles. The section measured at this point comprises 74 feet of beds. The lithologic details and the results of the chemical determinations obtained from the samples are given on Plate IV.

T. 26 N., R. 119 W., WYOMING.

Raymond Canyon cuts the Sublette Range in a steep, narrow, and rocky gorge transverse to the trend of the range and to the major axes of folding in the strata. The phosphate beds are exposed by prospecting in the NW. ¼ NE. ¼ sec. 6, T. 26 N., R. 119 W., by entry tunnels through the slide rock on the south side of the canyon. The cherty limestone forms a most prominent exposure in the canyon, standing nearly vertical like a massive rock wall about 80 feet thick, through which the creek passes in a gap hardly wider than the creek channel and the wagon road. The phosphate bed exposed in the principal prospects occurs high in the shaly division of the Park City formation, being relatively much nearer the cherty ledge than is the principal bed of the Montpelier section.

The following section was measured and samples were collected at the Raymond Canyon prospects:

Partial section of phosphatic beds in Raymond Canyon, Wyoming.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
42-A	Shale, grayish brown	8.9	19.5	4	5
	Limestone			6	
42-B	Phosphate, massive, compact, black, oolitic	32.0	70.1	3	1
42-C	Limestone, dark, fine grained	9.3	20.4	5	
				18	6

From this point southward the cherty ledge and phosphatic shales may be traced in almost continuous outcrop for 3 miles. These exposures cross the spurs running off from the main range, so that the outcrop itself follows an irregular profile, being intersected by the many lateral gulches draining this mountain slope. The principal prospects are found at the bottoms of the larger canyons and show the beds dipping east or west at steep angles.

All of the better-grade phosphate in this area is exceedingly compact and hard, so that it requires blasting in running in the entry tunnels. It has a dark color and displays oolitic texture, as elsewhere.

Coal Canyon, approximately on the section line at the south side of sec. 6, affords one of the most complete sections. The dark shaly beds were originally prospected for coal in several entries that extend to a considerable depth. An open-cut trench, partly caved, revealed a clear section for part of the series, from which the following measurements were made. The hillsides above the trench are covered with a heavy growth of vines and scrubby brush, and the outcrops there are concealed in slide rock.

Section in Coal Canyon, Sublette Mountains.

Field No. of specimen.	Description of beds.	P_2O_5	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
	Cherty limestone, massive; *Productus* abundant.	*Per cent.*	*Per cent.*	*Ft.*	*in.*
	Limestone, shaly and shattered			1	9
	Limestone, blocky			3	2
	Limestone, shaly, oolitic, crushed			1	10
	Limestone, black, shattered, fossils (*Chonetes*)			9	8
	Phosphate rock, shaly, oolitic, impure				5
	Limestone, black, coarse, and shale in part sandy			7	8
	Limestone, black, hard, with 3 inches of crushed shale, fossils			1	8
	Phosphate rock, oolitic (in Francis Canyon, 3′ 4″; 7.2 per cent)			5	10
	Limestone, dark gray, blocky, fossils			2	1
41-A	Shale, brownish-black, somewhat oolitic	27.0	51.1	3	9
	Limestone, gray, fossils			1	
41-B	Shale, brownish black, calcareous	16.3	35.7	8	8
	Limestone, dark gray, hard, fossils			2	
41-C	Shale, brown, with oolitic layers	Trace.	Trace.	2	
	Limestone			1	
41-D	Shale, soft brown, calcareous	11.9	26.1	1	3
	Limestone, gray, massive, fossils			4	
41-E	Shale, black and brown, thin bedded	16.8	36.8	8	
	Limestone, gray, shattered, oolitic at base			4	
41-F	Shale, grayish brown, calcareous, oolitic, medium to fine, in part sandy	16.4	35.9	6	
41-G	Shale, grayish brown, calcareous, sandy	12.0	16.3	4	
41-H	Phosphate rock, coarse, oolitic	26.0	56.9	4	6
41-I	Phosphate rock, oolitic in part	19.6	42.9	5	6
41-K	Limestone, grayish black, sandy	10.3	22.3	5	
	Interval covered to underlying limestone (about)			90	
	Total phosphate series (about)			184	

A "main bed" of rock phosphate, 4 feet 6 inches thick, in Jackson Canyon, about one-fourth of a mile south of Coal Canyon, was sampled, showing 32.7 per cent of phosphoric acid, equivalent to 71.6 per cent of tricalcium phosphate.

Prospects on the north side of York Canyon, in the NE. ¼ SW. ¼ sec. 18, revealed a bed of phosphate 4 feet thick, which showed on test 34.3 per cent of phosphoric acid, equivalent to 75.1 per cent of tricalcium phosphate. A prospect on the south side of the same canyon opens a bed of phosphate 5 feet 10 inches thick, giving 35.0 per cent of phosphoric acid, equivalent to 76.7 per cent of tricalcium phosphate.

A considerable series of beds was sampled and tested from prospects and exposures in Francis Canyon, in the NW. ¼ NE. ¼ sec. 19. Here two beds 3 feet 4 inches and 2 feet 4 inches thick ran 32.5 and 32.8 per cent of phosphoric acid (equivalent to 71.2 and 71.8 per cent of tricalcium phosphate). They are separated by an interval of 57 feet 6 inches. Numerous other beds contain more or less phosphatic material similar to that in the Coal Canyon section.

Just south of the prospects in Francis Canyon the outcrop of the cherty ledge associated with the phosphate beds appears to bend sharply eastward, so that this stratum flattens against the slope of the hill. This feature is probably of local significance, perhaps of entirely superficial character, but the phosphate has not been discovered south of this point, and it is assumed that the anticline or possible partial overthrust by which this outcrop has been brought up plunges here or is covered by the gravel bowlders and alluvial deposits. The structure of the main range south of Francis Canyon is apparently regular, forming a direct continuation of the structures in the northern part, but as the valley areas enter progressively farther into the range as it is followed toward the south, the outcrops are truncated at the valley margins, and further tracing of the phosphate becomes impossible.

AREA AND TONNAGE.

The total distance between the northernmost and the southernmost point of exposure of the phosphate beds is approximately 34,000 feet. The outcrop is not, however, directly traceable at the surface through the entire distance. The area under which the phosphate is assumed to be minable is narrow, owing to the steep inclination of the beds. In order to compare the tonnage of this district with that of the other areas in this region, estimates are presented on the basis of a minimum recovery of 5 feet of high-grade ore. The content of the bed on the east side of the anticline, computed to a depth of 2,000 feet along the bed, is 27,000,000 long tons. One-fifth of this amount, or 5,400,000 tons, is available from the area of double outcrops at the north end, and it is probable that prospecting by drilling might demonstrate the presence throughout the length of the range of the entire western flank of the fold. The total minimum quantity of phosphate in sight in the Sublette Mountain area, exclusive of the doubtful concealed western flank, is somewhat over 32,000,000 tons of 2,240 pounds.

PHOSPHATE AREA NEAR COKEVILLE.

LOCATION, ACCESSIBILITY, ETC.

The phosphate deposits near Cokeville, Wyo., are situated less than 2½ miles northeast of the town. The ready accessibility and the favorable situation of the beds have led to their early development, and this district is reported to have produced about 6,000 tons of high-grade phosphate rock to date. (See Pl. IX.)

GENERAL GEOLOGY.

The rocks of the Cokeville area correspond in the main with the stratigraphic section described under the general heading "Stratigraphy," beginning on page 469. The geologic structure involves an anticline broken at its axis and truncated on the east by a second and greater fault, which has introduced into the eastern part of the area beds of Cretaceous age. These beds, the Bear River formation, were called Laramie by the Hayden Survey[a] and were later described by T. W. Stanton[b] and assigned to a horizon in the late Cretaceous older than Laramie. The fold which brings up to outcrop the phosphate beds belongs to the same system of disturbances as the larger folds of the Sublette district, with which, geographically, the Cokeville area would naturally be considered as a unit. Commercially, however, the two areas are distinct and they are discussed separately in this report.

The oldest rocks in the Cokeville district are compact gray limestones (Madison limestone), whose Mississippian age is indicated by traces of zaphrentoid corals. Small areas of these rocks are found in the axis of the anticline, both north and south of Smiths Fork. Conspicuous outcrops occur on the west side of Signal Butte, 1½ miles east of Cokeville. The dips at this point are easterly and the outcrop is regarded as forming the east-central portion of the unsymmetrical anticline.

Ledges of the vitreous white to brownish Weber quartzite form the conspicuous jagged ribs of Rocky Point, and it is possible to trace individual beds of this formation up the western flank and over the crest of the anticline, but it is doubtful if the same beds can be identified on the eastern flank, owing to the readjustment and shifting produced by a nearly vertical break near the axis of the fold. A large portion of Signal Butte, including the summit, consists of a calcareous quartzite which should probably be referred to the Weber.

The Park City formation is best exposed on the east side of Rocky Point and the following section, measured by G. H. Girty, gives the amount and distribution of the rocks uncovered at this place, together with the phosphate content of the principal beds as determined by tests made in the present work:

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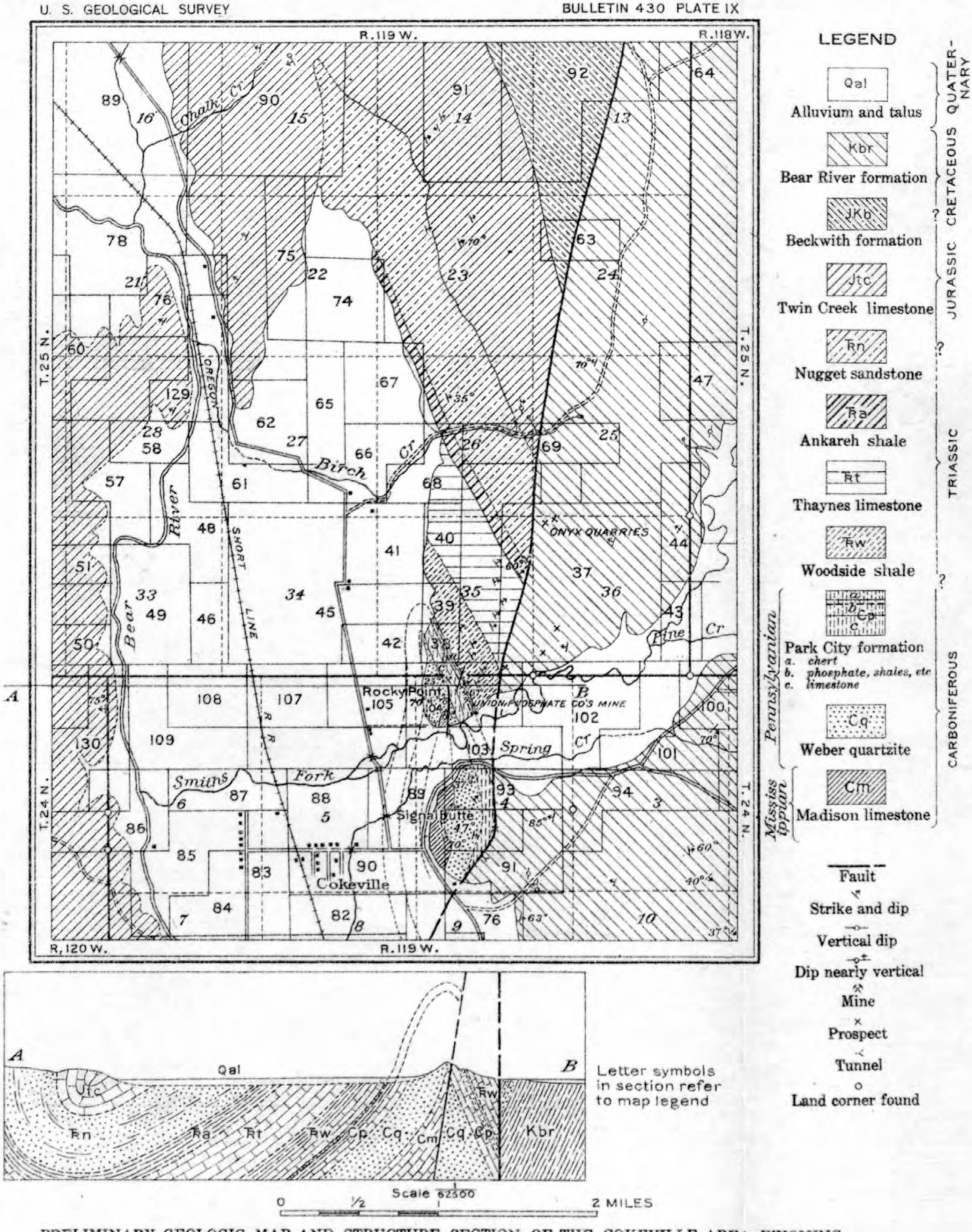
[a] Eighth Ann. Rept. U. S. Geog. and Geol. Survey Terr., 1876, pp. 144, 145.

[b] Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 98-115.



PRELIMINARY GEOLOGIC MAP AND STRUCTURE SECTION OF THE COKEVILLE AREA, WYOMING

Section of Park City formation near phosphate mines, Cokeville, Wyo.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
	Shales, reddish, base of Woodside shale. Chert, black, with occasional beds of clear, bluish-gray limestone; thickness estimated (fossils—*Productus*, *Chonetes*, and *Rhynchopora*)			100	
	Interval, concealed			6	
55-A	Shale, calcareous, hard	17.4	38.1	1	
	Limestone, black, siliceous (fossils)			4	
	Interval, concealed			2	
	Limestone, black, earthy			3	
	Interval, concealed, probably some limestone			20	
	Limestone, black, hard			1	6
	Interval, concealed			3	
55-B	Phosphate rock (?), oolitic, with *Lingula*	19.4	42.5	1	2
	Interval, concealed; in part shale, black, fissile			6	8
55-C	Shale, brown, fissile	.4	.9	3	
	Shale, brownish, sandy, somewhat massive, calcareous				10
55-D	Phosphate rock, black, oolitic, hard, and massive	28.5	62.4	1	1
55-E	Clay shale, brown, lower portion softer than upper	1.0	2.2	3	9
	Limestone, black, shaly			1	4
55-F	Shale, soft brown	.8	1.8	1	6
	Shale, calcareous, sandy, massive in part			5	3
55-G	Limestone, oolitic, in part shaly	22.2	48.6	1	11
55-H	Limestone, black, oolitic, hard, weathers brown	18.6	39.7	1	6
55-I	Phosphate rock, black, oolitic, hard	37.0	81.0	3	
55-K	Phosphate rock, grayish-black, hard	33.2	72.7	2	4
55-L	Shale, grayish-brown, soft	29.5	53.7	1	4
	Shale, brown, sandy, thin-bedded				6
	Limestone, brown, earthy, massive			2	1
55-M	Phosphate rock, gray, medium, oolitic	33.4	73.1	1	
55-N	{Shale, brown, somewhat oolitic	19.5	42.7	1	11
	{Shale, brown				3
55-O	Shale, grayish-black, oolitic	25.6	56.1		7
	Shale, somewhat oolitic			1	6
	Shale, sandy, black, oolitic, rather massive			1	8
	Shale, brown, massive			1	
	Limestone, light brown, earthy, massive			1	7
	Shale, phosphatic, contains nodules of limestone			2	3
	Limestone, dark gray, earthy			1	
	Shale, black, oolitic			4	2
	Limestone, black, hard, earthy (fossils)			4	10
	Shale, brown			3	6
	Limestone, brownish gray, earthy			1	6
	Shale, brownish black			1	10
	Limestone, brownish, soft, earthy, fairly massive			3	6
	Limestone, black, massive, weathers brown			2	
	Shale, black, fissile, weathers brown			4	2
	Limestone, grayish brown			1	3
	Shale, black, soft			1	6
	Shale, black, soft, contains some phosphatic concretions (fossils)			1	6
	Shale, soft, black			2	10
	Limestone, black			1	
	Shale, black, weathers brown			2	3
	Interval, concealed			45	
	Limestone, gray, siliceous, grading below to glassy white Weber quartzite			300	
	Approximate total thickness			571	4

For purposes of graphic comparison, this section is included on Plate IV. The remarkably persistent characteristics of the Park City formation are again illustrated by this section. The lower portion consists of sandy limestone beds overlain by a series of phosphatic shales containing lenticular, fetid limestones and beds of high-grade phosphate rock, and these are in turn overlain by the chert, which here makes a prominent hogback. The position of the outcrop of the main phosphate bed can often be readily determined for prospecting by measuring from this chert marker.

On the east limb of the more or less broken anticline in the northern part of the area shown on the map the section overlying the Park City formation in normal sequence is continuous to the Beckwith formation. Directly east of the phosphate mines, however, the fault has cut so far to the west that the base of the Thaynes limestone is barely included in the section there. The formations overlying the Park City and west of the fault are typical Woodside shale, Thaynes limestone, and Ankareh shale.

The Bear River formation is composed mainly of dark shales, carbonaceous beds, gray and buff sandstones, and brownish conglomerate. The carbonaceous beds have been prospected in various places for coal, but no beds of economic importance appear to have been found. Beds of probable Eocene age cap several of the higher hills and ridges in places, but are of no recognized economic importance, and their mapping would have served only to obscure the representation of the harder rock formations. The alluvium of Bear River valley and the aprons of wash bordering the hills form an effective blanket over a large part of the area west of the anticlinal axis and necessarily render hypothetical all conclusions concerning the distribution of underlying bed-rock formations.

For purposes of discussion of the geologic structure the area is naturally divided into two structural units by a major fault crossing the area from north to south. This fault is of the normal or gravity type and its maximum displacement is along the axis of the anticline where presumable Cretaceous rocks lie against the Mississippian limestone. This contact is concealed by the alluvial deposits, however, and the maximum exposed displacement is found in the vicinity of the prospects on the southeast side of Signal Butte. Here the Park City formation lies against the Cretaceous. The stratigraphic displacement decreases in amount toward the north, and it is possible that the fault passes into a fold in that direction.

The eastern structural unit is composed of contorted and for the most part steeply dipping rocks of the Bear River formation, and in that area the phosphate deposits, if present, lie at a depth of more than 9,000 feet. The western unit comprises the sharp anticlinal fold mentioned above, which brings up the phosphate-bearing formation. The eastern portion of the anticline is clearly shown by the areal distribution and the prevailing easterly dips of the formations involved. West of the anticlinal axis in Rocky Point the phosphate is concealed by the alluvium and wash and may be so disturbed that any attempt at approximation of its position would prove of slight value. An endeavor has been made, however, to indicate on the map a hypothetical position and trend for the western or suballuvium area of the Park City formation. The beds are shown where they would occur, provided the dips of the intervening strata in the western limb correspond to the dip readings obtained on the west bank of Bear River and on the west side of Rocky Point. It therefore seems probable that the underlying structure is somewhat as represented and that the actual position of the concealed phosphate could be determined by a series of test borings. No data concerning the thickness of the alluvium cover in this locality are available, but it may be at least 200 feet thick and so permeated with water that the expense of mining the phosphate under such conditions would be great and not warranted under present circumstances.

DEVELOPMENT.

The mine at Cokeville, which has been developed by the Union Phosphate Company, consists of a series of tunnels run in on the strike of the main phosphate bed. The mining practice followed involves the breaking of the rock by overhead stoping; stopes are opened above the several tunnels through upraises; the rock is hard, and air drills are used in putting in the holes; the breaking is done with giant powder; the stopes are set with timbers and the rock or ore is allowed to settle between the timbers and drawn off by chutes into cars that in turn dump into the lower stopes, which are used for storage purposes, the ore being finally drawn off into the car on the lower level, which dumps into the outside bins for loading the wagons. Little work has been done in the upper tunnel, but the other three are each approximately 1,000 feet in length.

Offsets were noted in the second and lowest tunnels. One has about 6 feet throw at a distance of approximately 50 feet from the entrance. Another, about 1,050 feet in and about 35 feet back from the face of the tunnel, shows a displacement of unknown throw. An examination of the surface above the mine revealed the existence of a fault—probably the same one that shows in the deeper parts of the tunnels, with a direction of N. 15° E. and a horizontal offset of about 55 feet to the northeast on the north side.

The section of the "main beds" is fairly constant, and its details and the distribution of the phosphate content are given in the section of the Park City formation on page 505. The portion mined and shipped at present is 5 feet 4 inches thick with an average content of over 35 per cent of phosphoric acid, equivalent to 75 per cent of tricalcium phosphate.

A number of prospects have been opened in the search for phosphate deposits on the southeast side of Signal Butte, south of Smiths Fork. The northernmost is located in the NW. ¼ SE. ¼ sec. 4, and consists of a pit in a yellow, claylike material and an east-west trench showing a brecciated portion of the phosphatic rocks of the Park City formation. In tract 91 there are three or four small openings and a tunnel about 80 feet in length, running westward in a brecciated zone of phosphatic rocks, among which, however, no clearly defined bed of high-grade material was observed. The pronounced brecciation noted in all openings in this part of the area is interpreted as indicating the proximity of the fault plane.

TONNAGE.

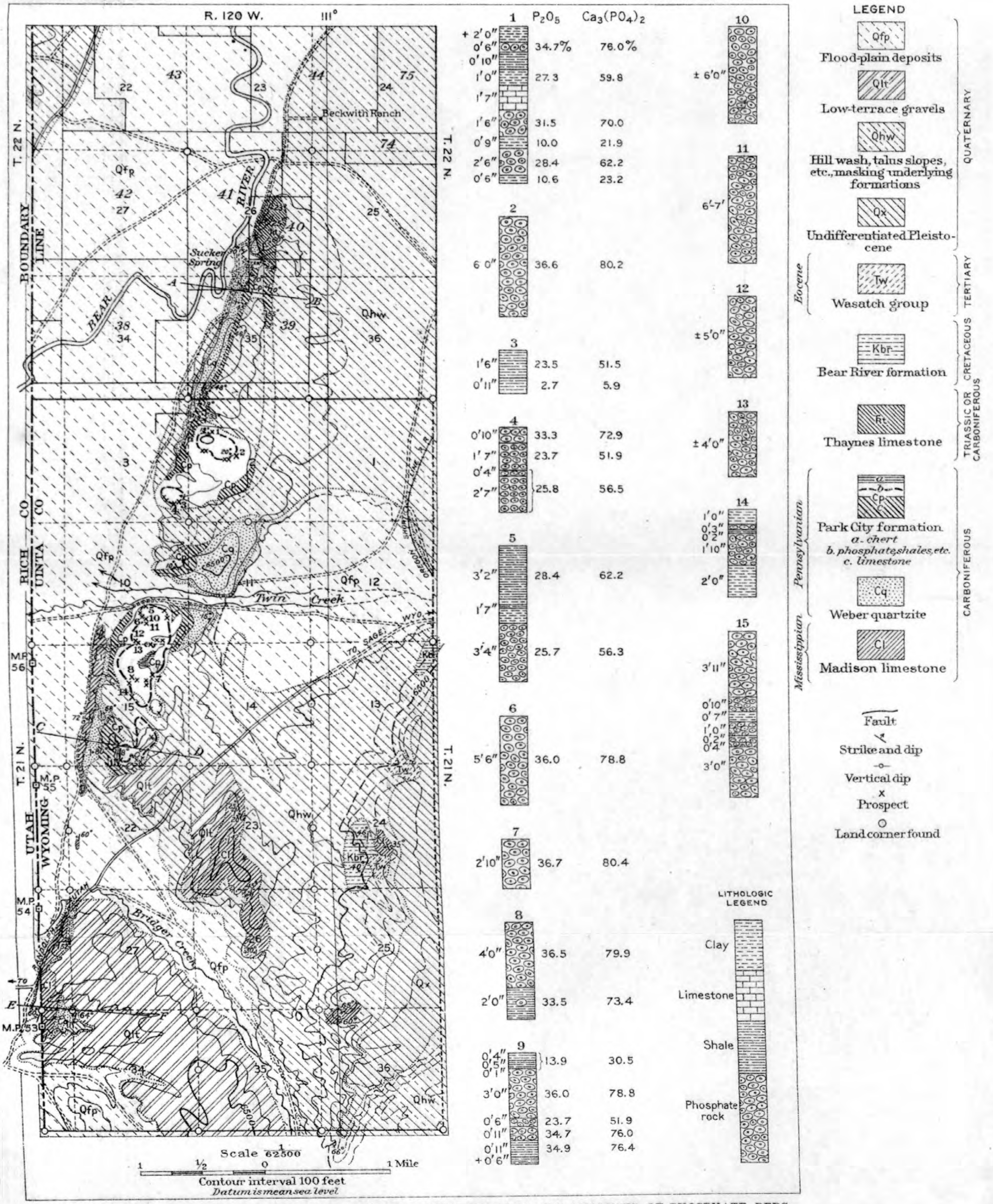
The length of the traced outcrop of the main phosphate bed on the east side of the anticline north of Smiths Fork is approximately 3,000 feet. A consideration of the tonnage of the bed, based on recovery of 5 feet of the total thickness to a depth of 2,000 feet along the bed, yields a total of 2,400,000 tons, of 2,240 pounds, as the available quantity of phosphate in the Cokeville area. This represents a minimum estimate of the tonnage of high-grade phosphate rock in the area and excludes that portion of the ore lying above the water level in and about the mine.

The character of the deposits south of Smiths Fork is too problematical and the extent of development has been too insufficient to permit an estimate of the phosphate contained in them. The amount of rock within 2,000 feet of the surface in the concealed western portion of the anticline, provided that it occurs in a normal anticlinal structure, probably exceeds by about four times the figures of the above estimate.

PHOSPHATE NEAR COKEVILLE PRESUMABLY DERIVED FROM THE TWIN CREEK LIMESTONE.

In a hasty review of the area southwest of Cokeville a piece of rock picked up at the witness monument of the quarter-section corner on the west side of sec. 36, T. 24 N., R. 120 W., Wyoming, was found on test to be rock phosphate equivalent to about 70 per cent bone phosphate grade. This rock was collected with a considerable number of other specimens from oolitic limestone of the Twin Creek formation, such as is observed in many places throughout the Idaho, Wyoming, and Utah field. Most of the dark-bluish oolitic limestone specimens, many of which represented rock in place, proved to contain but a negligible trace of phosphoric acid. The specimen of commercial phosphate was derived from float, and being of angular form, had probably not been transported far. This phosphate much resembles the oolitic Jurassic beds found in natural outcrop near by, and is thought to have been derived from this portion of the formation. No outcrops of the older or Carboniferous phosphates are now known nearer than those at the Cokeville mines, a distance of more than 6 miles. The Twin Creek phosphate beds have not, however, been found in place.

A second visit to the locality has not served to identify the original bed. More float of practically the same material was collected on



MAP OF BECKWITH HILLS PHOSPHATE AREA, WYOMING, WITH SECTIONS AND ANALYSES OF PHOSPHATE BEDS the township line, about 150 feet west of the southwest corner of sec. 36, which is about on the strike of the same beds and seems to indicate the continuity of such a phosphatic horizon through at least that distance. The following analyses were obtained from the specimens collected:

Float found at the quarter section corner on the west side of sec. 36, T. 24 N., R. 120 W., Wyoming (phosphate rock, dull brownish, obscurely oolitic, fragments of 4-inch stratum showing bluish-white coating, as on float of phosphate in other areas): 30.8 per cent of P_2O_5, equivalent to 67.4 per cent of $Ca_3 (PO_4)_2$.

Float found near the southwest corner of sec. 36, T. 24 N., R. 120 W., Wyoming (phosphate rock, dull brownish, obscurely oolitic, indistinguishable from specimen described above): 32.6 per cent of P_2O_5, equivalent to 71.4 per cent of $Ca_3 (PO_4)_2$.

Further search in other parts of the field for phosphatic beds in the Twin Creek limestone has not yet been rewarded, but it must be acknowledged that this search has not been very thoroughly prosecuted.

BECKWITH HILLS AREA.

LOCATION AND DEVELOPMENT.

The Beckwith Hills phosphate area is situated in Tps. 21 and 22 N., R. 120 W., on the western border of Wyoming. (See Pl. X.) The area represents a northern outlier of the Crawford Mountain district, but has been reduced by erosion to a much greater extent than that district, so that the phosphate-bearing formation covers at present only a small portion of the area originally occupied by it in this region.

The Beckwith Hills consist of a series of low hills lying north, somewhat east, of the Crawford Mountains and having a trend which coincides with the general strike of the rock formations. The hills are separated from one another by the gaps of Twin Creek and Bridger Creek.

The mining developments in the district are limited to prospecting work done in connection with the annual assessment requirements of the mining law. Many of the claims are located under both the placer and the lode laws, and in most cases the two locations have been made by conflicting parties. So far as known, none of the claims have been patented.

The nearest shipping point is Sage station, on the Oregon Short Line Railroad, and the average haul is about 4 miles, over a practically level road.

GENERAL GEOLOGY.

The data available for deciphering the structural conditions existing in this area are more or less fragmentary, because of the extensive cover of Quaternary deposits, and all conclusions concerning the structure are necessarily hypothetical. An attempt has been made to solve the problems by working out the simplest solution that is consistent with the observations obtained in the field.

A portion of the Park City formation left by erosion appears to lie along either the axis or the lower flanks of a syncline which ranges from a nearly upright to an overturned, nearly horizontal or recumbent position in different parts of the area. This change is shown by

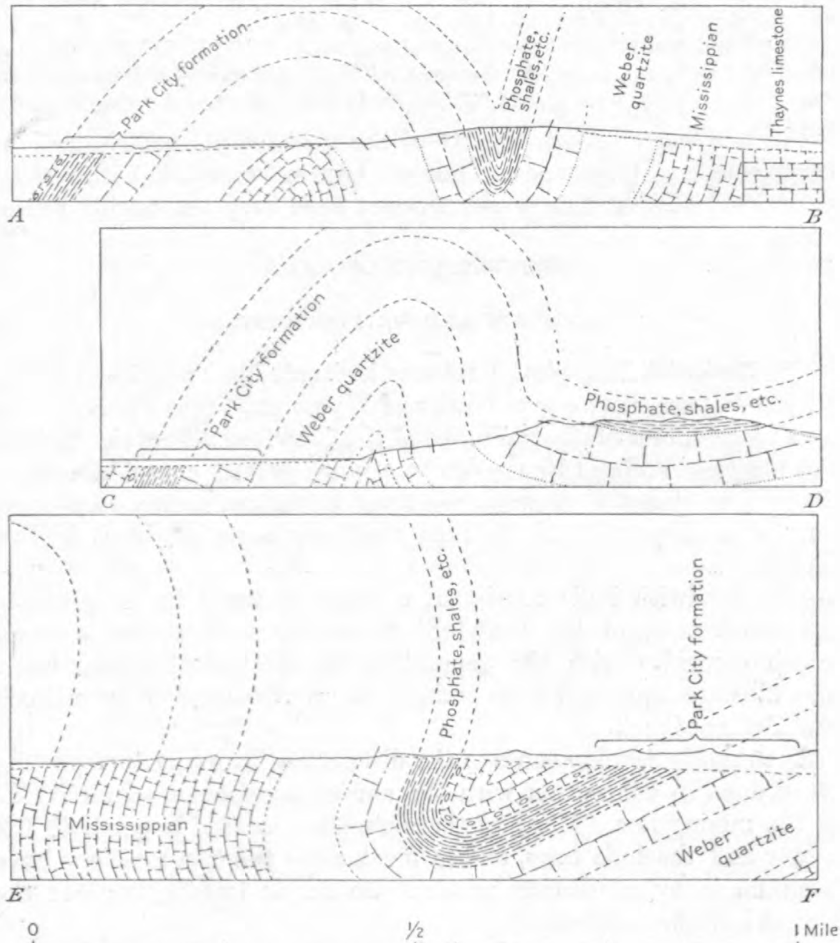


FIGURE 43.—Diagrammatic structure sections of the Beckwith Hills area, Wyoming. (See Pl. X.)

the graphic structure sections in figure 43, which illustrate conditions across the northern, middle, and southern parts of the area. The synclinal structure is assumed to be continuous between the sections. A detailed examination of the phosphate prospects showed minor plications and rolls, too small for representation on the map and of such a character that they will not cause any great amount of trouble in the development of the principal bed. A fault was found which cuts across the northern apex of the syncline and brings the Thaynes limestone into juxtaposition with the arenaceous limestone of the Park City formation underlying the phosphate-bearing shales. The extension of this fault in both directions is concealed by the Quaternary deposits.

The outcrop of the Park City formation is especially conspicuous along the western margin of the Beckwith Hills. The phosphatic rocks consist of a succession of about 200 feet of black and gray shales and gray, compact, fetid limestones, usually lenticular, with at least one 5 foot to 5 foot 6 inch bed of high-grade, coarsely oolitic phosphate rock nearly at the center of the phosphate-bearing zone and probably corresponding to the main bed in the Crawford Mountain district. So far as known, the high-grade bed is not included in that portion of the syncline present in T. 22 N., R. 120 W. The outcrop of the main bed in the township to the south is indicated on the map (Pl. X), and the results obtained in the examination of the exposures in the various prospects are summarized in the following statements.

PHOSPHATE BEDS

A number of prospects on the south side of the hill in sec. 2 indicate that the thickness of the bed here averages about 6 feet and that it consists of a gray, coarsely oolitic phosphate rock containing 36.6 per cent of P_2O_5, or 80.2 per cent of bone phosphate. The prospect on the north side of the same hill shows a totally different section, apparently of a lower bed, which is as follows:

Partial section of phosphate beds in sec. 2, T. 21 N., R. 120 W.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
	Clay, with fragments of phosphate rock			1 2
81-A	Phosphate rock, gray, coarsely oolitic	34.7	76.0	6
	Shale, red and yellow			3
	Shale, gray, soft			3½
	Shale, reddish gray			4
81-B	Phosphate rock, brownish gray, soft	27.3	59.8	1
	Limestone			1 7
81-C	Phosphate rock, coarsely oolitic, soft	31.5	70.0	1 6
81-D	Phosphate rock, shaly, gray, brown, soft	10.0	21.9	9
81-E	Phosphate rock, dark gray, oolitic	28.4	62.2	2 6
81-F	Phosphate rock, shaly, brown	10.6	23.2	6

The small hill in the SE. ¼ sec. 3 has been prospected by several entries, and the following section is a combination of the measurements obtained in the two eastern prospects:

Partial section of phosphate beds in sec. 3, T. 21 N., R. 120 W.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
84-A	Shale, gray, soft	23.5	51.5	1 6
84-B	Shale, gray, shaly, soft	2.7	5.9	11
84-C	Phosphate rock, gray, oolitic, soft	33.3	72.9	10
84-D	Phosphate rock, light gray, oolitic, soft	23.7	51.9	1 7
84-E	Phosphate rock, coarsely oolitic (*Ft. in.* 4); Phosphate rock, gray, hard, grading to black; pebbly at base (2 3)	25.8	56.5	2 7

A large number of prospects have been opened on the hill immediately south of the Twin Creek gap. One of the best sections exposed is the following, measured in a tunnel in the NW. ¼ SW. ¼ sec. 10:

Partial section of phosphate beds in sec. 10, T. 21 N., R. 120 W.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
83A	Phosphate rock, mostly soil-like, but contains some oolitic material	28.4	62.2	3 2
	Shale, red and gray, fine grained			7
83B	Phosphate rock, gray, oolitic	25.7	56.3	8
	Phosphate rock, reddish gray, fine grained			10
	Phosphate rock, gray, oolitic			1 10

The southernmost of the prospects, in the SE. ¼ sec. 15, shows a better and perhaps a more typical section:

Partial section of phosphate beds in sec. 15, T. 21 N., R. 120 W.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
87A	Phosphate rock, dark gray to black, oolitic, hard	13.9	30.5	4
	Shale, brown, earthy, thin, black			5
87B	Pebble bed	36.0	78.8	1
	Phosphate rock, dark gray to black, massive, hard			2 11
87C	Phosphate rock, fine grained, oolitic, hard	23.7	51.9	6
87D	Phosphate rock, black, coarsely oolitic	34.7	76.0	11
87E	Phosphate rock, light gray, sandy and shaly	34.9	76.4	10
	Shale, soft, iron-stained			1

The above, together with the other analytical results obtained in this area, are shown graphically on Plate IV. It will be noted that the prospecting in the Beckwith Hills has been limited to the main bed, and additional trenching would be necessary to determine the character and amount of other beds and lower-grade phosphate rock present. It is, however, probably comparable to the material found in other districts where detailed sections of the entire succession have been made. (See, for example, the series of tests recorded in the table on p. 477.)

AREA AND TONNAGE.

The area of known phosphate land in the Beckwith Hills district is estimated to comprise approximately the following acreage:

Phosphate land in Beckwith Hills district.

	Acres.
Section 2	27
Section 3	8
Sections 10 and 15 combined	101½
Section 15	25
	161½

Additional areas of land underlain by phosphate are suspected in secs. 22 and 34, but no data are available for estimating their extent. Such data can not be obtained except by shafting or drilling through the terrace cover. All of the phosphate in the main bed in the proved area must be regarded as the minimum amount available, and computation on the basis of an average thickness of 5 feet yields a total minimum in round numbers of 2,800,000 tons of 2,240 pounds in the Beckwith Hills area.

The portion of the phosphate-bearing section below this bed undoubtedly contains an even greater amount of material which may be regarded as ultimately available, and the tonnage of the concealed portion of the phosphate beds mentioned above can not be considered because of lack of data.

UTAH.

CRAWFORD MOUNTAIN AREA.

LOCATION, ACCESSIBILITY, ETC.

The Crawford Mountains include what is at present the most extensively prospected and perhaps one of the best known and most readily accessible of the larger phosphate areas that has yet been brought to public attention. These mountains lie in the eastern side of Rich County, Utah, extending into southwestern Uinta County, Wyo. If the Beckwith Hills are considered as a separate area all the known phosphate deposits in the Crawford Mountains lie on the Utah side of the state line. The prospected outcrops are situated in parts of T. 9 N., R. 7 E.; T. 10 N., Rs. 7 and 8 E.; and T. 11 N., Rs. 7 and

8 E., all referred to the Salt Lake guide and meridian, Utah. (See Pl. XI.)

The beds of the Beckwith Hills were without doubt originally continuous with the deposits of the Crawford Mountains, but are now separated from them by gaps or intervals from which erosion has removed all the phosphate-bearing rocks. On account of the isolation of the Beckwith Hills tracts, they are described as an independent area.

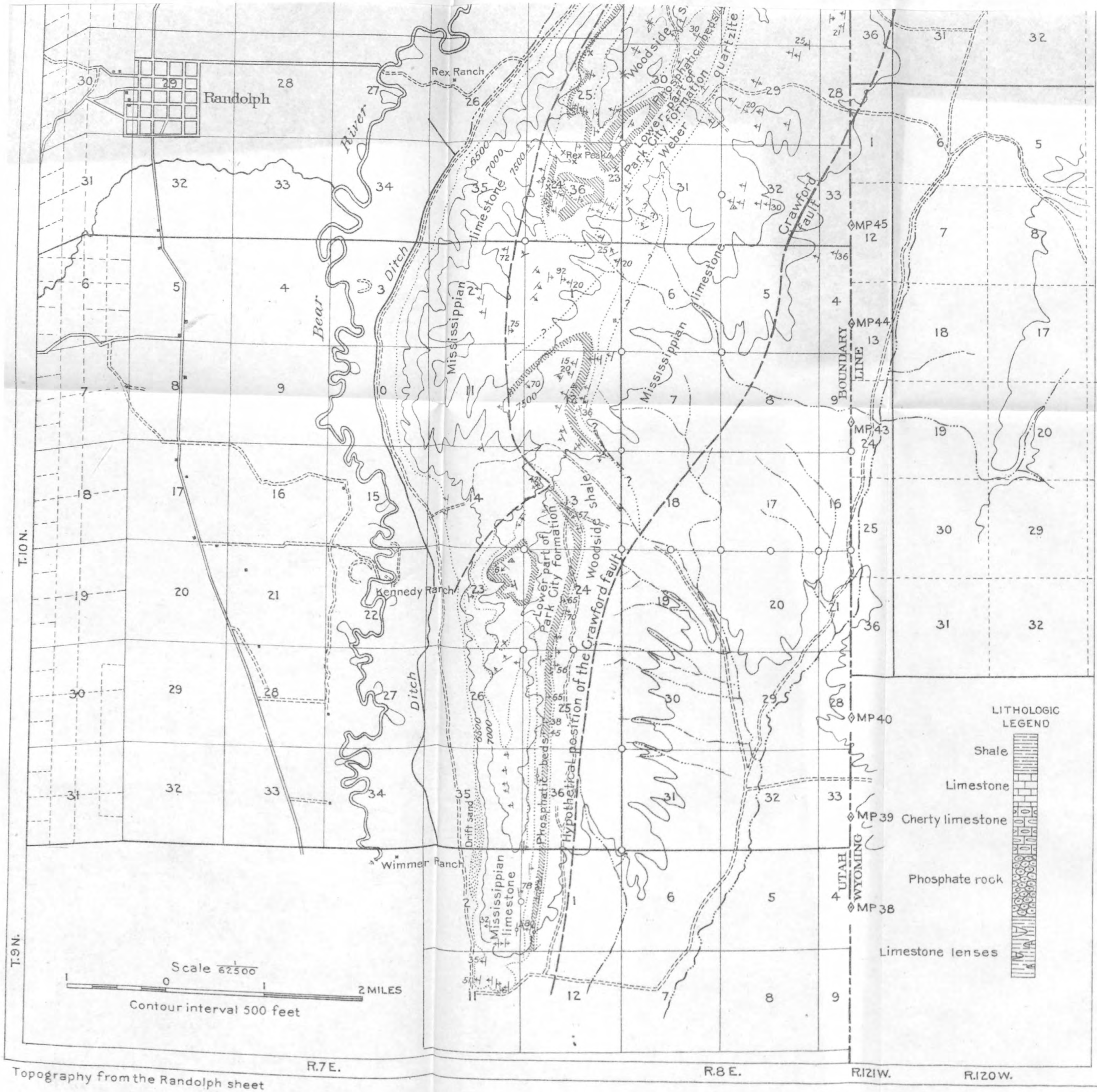
The shipping point nearest the Crawford Mountain phosphate deposits at the present time is Sage, Wyo. The whole area is, however, easily accessible by railroad routes, for it is practically surrounded by low valleys, especially by the flat bottom lands of Bear River, which reach within a very short distance of the prospected area.

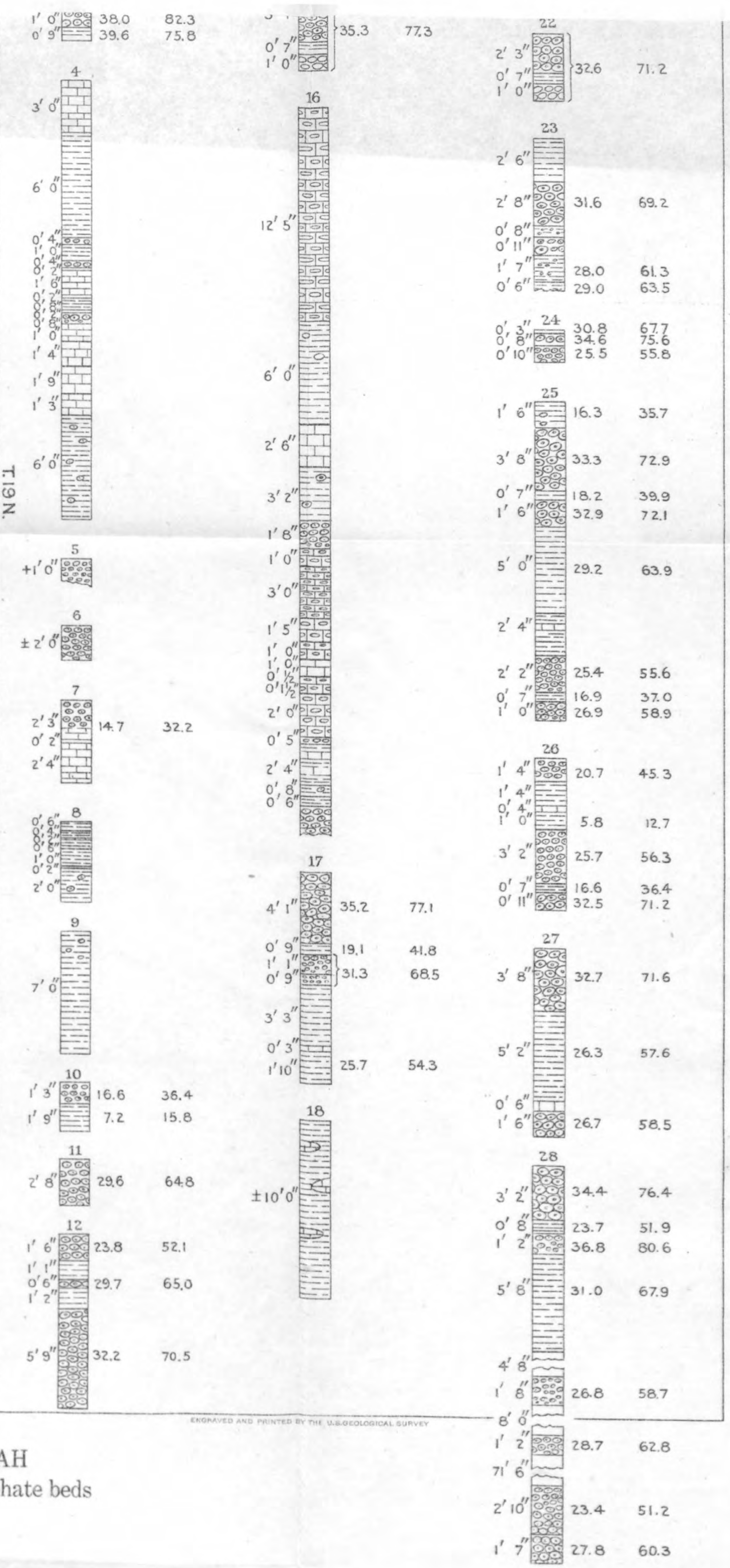
GEOLOGY.

The phosphate beds are typically developed in the Crawford Mountains. The relations of the phosphate-bearing strata to both overlying and underlying rock formations, though involved in more or less structural complexity, are nevertheless clearly revealed throughout the area, and it is, therefore, an excellent place to study the geology of these deposits.

The stratigraphic sequence, as has been described in a general way on pages 469–470, includes the section from the Mississippian or older limestones at the base to the Woodside or possibly lower Thaynes, the latter being the remnants included along the axes of the deeper parts of the major synclines. Small patches of presumably Wasatch and late surficial deposits, such as gravel, bowlders, and sands and alluvium, are not necessarily differentiated so far as their practical bearing on the occurrence and accessibility of the phosphate is concerned. The principal and more complete sections of the Park City formation, including the phosphate, are illustrated in a graphic way in Plates IV and XI.

The geologic structure of the Crawford Mountains is evidently related to the general structure of the whole region studied, being produced by great compression caused by thrust movements originating from the west and resulting in closed folds of north-south extension and overthrust faults, in which the older rocks ride up and over the younger, all dipping in the same westerly direction. The northern half of these mountains consists on the west flank of an anticline, apparently developing into an overthrust fault or being overridden and concealed by an overthrust near the middle of the west face of the range. The continuous syncline extending from the northern extremity of the range to the highest summit at Rex Peak parallels the western marginal anticline and includes most of the prospected





GENERAL GEOLOGIC MAP OF THE CRAWFORD MOUNTAINS, UTAH

showing extent of known phosphate outcrops, with sections and analyses of phosphate beds phosphate deposits. East of the syncline that contains the phosphate similar folds in the older rocks, including the Mississippian rocks, are brought to the surface, so that these evidently form the principal axis of the range. On the east these Paleozoic limestones abut directly against the later Tertiary or Cretaceous and Tertiary rocks, which are assumed to have been brought into this relation by a fault, the exact character of which has not been determined. This fault is also supposed to mark the entire western margin of the Crawford Mountain area, and from this fact it has been referred to by Veatch[a] as the Crawford fault. Its position is in greater part obscured by the covering of Quaternary gravels and silts, but in at least one place, in the SE. ¼ sec. 32, T. 11 N., R. 8 E., the Cretaceous sandstone is exposed in contact with the Palezoic limestone. In a less distinct way its position is traced by the alignment and abrupt termination of the higher ridges exposing the older rocks, to the east of which the low rolling valleys are presumably eroded in the softer Tertiary strata.

In the southern half of the Crawford Mountains the structure is not so regular as that to the north. South of Rex Peak the folds as a whole rise so that the phosphate beds are found only in patches on the high tops and are eroded entirely for an interval of a mile or more. On the west flank of the mountains the overthrust of Mississippian limestone broadens, forming a precipitous rocky wall near the middle of the range. The phosphatic beds reappear in a somewhat irregular synclinal fold about 2 miles south of Rex Peak, and from this point they have been traced to the extreme south end of the mountains, following the west side. The southern extremity of the Crawford Mountains so far as exposed is evidently a comparatively simple anticline, of which the west flank is steep and in part overturned. All these relations are brought out to a certain extent by the areal distribution of formations and the dip and strike symbols shown on Plate XI.

PROSPECTS AND DEVELOPMENT.

GENERAL STATEMENT.

The patented claims in the phosphate lands, as shown on the map, are located in the northern part of the area. These claims are of the lode type and therefore follow the outcrops of the phosphate beds on either flank of the syncline in which the deposits are folded. Other claims have been staked covering a large part of the outcrops south of the patented ground to a point about 3 miles south of Rex Peak, beyond which, so far as known to the authors, no claims exist, nor have the deposits been locally recognized.

[a] Veatch, A. C., Geology and geography of a portion of southwestern Wyoming: Prof. Paper U. S. Geol. Survey No. 56, 1907, Pl. III.

Besides the recognized outcrops others may be inferred from the structure. In the northern part of the area several small prospects at the Enberg ranch have revealed the presence of the phosphate on the west flank of the marginal anticline. The outcrops are situated low on the hill slope, near the level of the valley bottom, and are probably covered by slide or valley fill throughout the greater part of their extent. There is every reason to believe that beds of high-grade phosphate are present on this side of the mountains and will at some time prove valuable for mining, although no claims have yet been staked on this outcrop. At the south end of the range the apparently simple anticlinal structure revealed in the Mississippian and possibly older limestones exposed suggest an outcrop of the phosphate on the west side of the range, somewhere in the river bottom lands, perhaps near the Wimmer ranch, corresponding to the outcrop as discovered along the east foot of this ridge. An attempt to judge with any degree of accuracy the position of these concealed outcrops is probably not warranted from the data available, but it is entirely possible that such beds may at some time be discovered either by search or by accident.

T. 12 N., R. 8 E.

The known occurrence of phosphate in T. 12 N., R. 8 E., is limited to secs. 32 and 33, although by extension of the outcrops northward in the same general trend as the structures to the south the beds may be and doubtless are continuous into secs. 29 and 28 and to the northeast, crossing the state line into Wyoming.

The main phosphate bed that is worked is well exposed in numerous prospects and in the mine at the extreme north end of the exposed beds. Similar entry tunnels have been run in on both the east and west flanks of the syncline; that on the east, the more extensively worked, is known as the Arikaree mine, and that on the west as the Mandan.

The Arikaree mine is located in lot 2, sec. 33, about 1,700 feet S. 30° W. from the 52-mile post on the Utah-Wyoming state line. Rock phosphate has been mined here for a number of years. The material is shipped to the American Agricultural Chemical Company's fertilizer plant near Los Angeles, Cal., with whom the Bradley Brothers, owning the Crawford Mountain properties, are allied. The mine consists of a main tunnel 450 feet in length and a drift following the main phosphate bed for about 300 feet; a moderate amount of ore has been worked out in stopes above the drift.

The bed worked measures from 53 to 60 inches in total thickness, but is divided into two parts by the so-called "gray streak." This is a leaner parting, 2½ to 7 inches thick, and separates about a foot of the high-grade ore at the bottom of the bed from the upper part.

The most massive or less shaly material and that most coarsely oolitic is considered the best ore. The rock of the workable bed is dark gray when freshly taken out, drying to a light gray in the air. It is of fine to medium and in part coarsely oolitic texture and shows both massive and shaly structure.

The dip of the beds in the Arikaree mine is 50° W. and the strike N. 32° E. In mining the bed the upper bench is first taken out and the entry and chutes are drawn clear. Then the lean-ore streak is dug out and discarded, the entries being similarly cleared, after which the lower bench is mined and the entry again advanced on the upper part of the bed. Thus the discarding of a few inches of lean material adds materially to the expense of mining in an effort to hold the product at the highest possible grade.

A section of the main bed is as follows:

Representative section of main bed at Arikaree mine, Crawford Mountains.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
93-A	Phosphate, gray, coarsely oolitic	29.4	64.4	1	9
93-B	Phosphate, gray, oolitic	37.6	82.3	1	4
93-C	Phosphate, brown, shaly, somewhat oolitic (lean streak)	21.4	46.9		7
93-D	Phosphate, gray, medium to coarse, oolitic	38.0	82.3	1	
93-E	Phosphate, fine-grained, shaly, somewhat oolitic (not mined)	34.6	75.8		9
	Average	32.2	70.3	[a] 5	5

[a] Total.

The Mandan mine, now abandoned, enters the main phosphate bed on the west side of the syncline. It consists of a single entry tunnel run in about 250 feet, of which the first half is through slide rock. Like the Arikaree, it is at the extreme north end of the visible outcrops of phosphate. It is situated in lot 1, sec. 32, about 1,950 feet S. 70° W. of the 52-mile post on the Utah-Wyoming state line, and is about 1,300 feet northwest of the Arikaree. The outcrops of the main bed are about 1,200 feet apart across the syncline at this place. The west flank of the syncline is steep, either vertical or locally overturned; in the mine the strike is N. 24° E. and the dip 81° to 82° W. The east flank dips about 50° W., as stated. It seems likely, therefore, that the bed is not more than 600 or 800 feet below the surface at its deepest point in this part of the field, and the total breadth of the minable deposit between the outcrops is perhaps approximately 2,000 feet.

Samples and measurements of the phosphate and associated beds exposed in the Mandan mine gave the following results:

Partial section of phosphate beds at the Mandan mine, Crawford Mountains.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
95	Main bed:			
	Phosphate, gray, coarsely oolitic	33.8	74.0	3 6
	Phosphate, lean streak			8
	Phosphate, gray, fine, oolitic			1 6
96-G	Shale, phosphatic, gray	31.5	69.0	9
	Shale, brown, calcareous			4 1
96-F	Shale, brownish gray, calcareous	13.5	29.6	1 9
96-E	Phosphate, coarsely oolitic, gray	30.6	67.0	10
	Limestone			1 1
96-D	Phosphate, oolitic, gray	25.9	56.7	1 6
96-C	Phosphate and shale, alternating bands	29.4	64.3	3 3
	Shale, brown			1 6
96-B	Phosphate, oolitic, calcareous	31.0	67.9	1 3
	Limestone			2 5
96-A	Phosphate, dark gray, oolitic	24.9	54.5	1 6
				25 7

Numerous other prospects extending southward from the Arikaree and Mandan mines trace the outcrop of the main phosphate bed visibly. An open cut in lot 5, sec. 32, exposed an excellent section of the bed on the east flank of the syncline and a series of representative samples was collected at this place, which is on the Sioux lode claim.

Representative section including the main bed on Sioux claim, Crawford Mountains.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
92-A	Shale, massive, brown, calcareous, earthy	1.0	2.2	1
	Shale, calcareous			5 9
92-B	Phosphate, dark gray, coarsely oolitic	10.7	23.4	1 4
	Shale, calcareous			9
92-C	Phosphate, dark gray, coarsely oolitic	30.5	66.8	7
	Shale			1
	Main bed:			
92-D	Phosphate, massive, dark gray, oolitic	35.7	78.2	3 7
	Shale, brown			3
92-E	Phosphate, massive, gray, oolitic	36.4	79.7	1 8
				15 11

The outcrops on the west flank of the syncline have been prospected in the gulch just east of the Enberg ranch, about half a mile from the house. It is reported that ore was taken from this place when the first shipments were made in this district. Two beds are opened in old drifts, but the section as a whole is not well exposed.

The small pits revealing the third outcrop of the phosphate beds near the Enberg house have already been mentioned (p. 516) in connection with the discussion of the structure at this place. The showing was not sufficient to warrant measurement or sampling.

T. 11 N., R. 8 E.

The syncline bearing the phosphate beds in the northern Crawford area broadens as traced to the south through T. 11 N., R. 8 E., and the reserve of phosphate correspondingly increases. The axis of the syncline is for the most part marked by a valley or depression of the surface, this feature becoming most marked toward the south as it approaches Rex Peak and the summit of the range. Thus the beds that outcrop on either flank dip toward and underlie the intervening valley area. The phosphate beds are protected from erosion by the upper cherty limestone of the Park City formation. The valleys along the axis of the syncline are excavated in the softer shales of the Woodside. Probably the greater part of the outcrop of the phosphate rocks in this township is covered by claim locations, mostly of the lode type, although there are also duplicate locations, as elsewhere, made in both placer and lode form.

The distribution of the beds is represented by the map (Pl. XI). The following sections measured and samples taken for analysis are probably representative and serve for partial comparison with the Arikaree and Mandan sections already described.

Section of phosphate and associated beds on Tuscarora claim, in NW. ¼ NW. ¼ sec. 17, T. 11 N., R. 8 E.

	Ft.	in.
Phosphate beds in upper part of section not well exposed.		
Shale or hard clay rock, brown and grayish		6
Phosphate (main bed), hard, massive, uniformly oolitic (1-inch coarse pebbly layer at top)	5	9
Shale, brown to black, very thin bedded, oolitic in thicker bands, evidently phosphatic	5	3
Shale, like above, but thicker bedded		10
Limestone, massive, single stratum	2	3
Phosphate, alternating thick and very thin bedded	2	8
Phosphate, hard, coarsely oolitic, black, single stratum	1	
	18	3
More phosphate underlying, not exposed.		

Section of phosphate and associated beds in Brazer Canyon, in NW. ¼ SE. ¼ sec. 18, T. 11 N., R. 8 E.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness. Ft.	in.
		Per cent.	Per cent.	Ft.	in.
100-A	Phosphate, dark gray, coarsely oolitic	32.7	71.6	3	8
100-B	Phosphate, brown, shaly	26.3	57.6	5	2
	Limestone				6
100-C	Phosphate, brownish gray, oolitic	26.7	58.5	1	6
				10	10

Section of phosphate and associated beds in Brazer Canyon, "Otto claim," approximately in NE. ¼ NE. ¼ sec. 19, T. 11 N., R. 8 E.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
	Main bed:	*Per cent.*	*Per cent.*	*Ft. in.*
97-A	Phosphate, dark gray or black, massive, coarsely oolitic	34.9	76.4	3 2
97-B	Phosphate, shaly, brown, weathered, oolitic	23.7	51.9	8
97-C	Phosphate, dark, almost black, oolitic	36.8	80.6	1 2
97-D	Phosphate, brown, shaly, finely oolitic	31.0	67.9	5 8
	Interval concealed, probably shaly			4 8
97-E	Phosphate, or limestone, dark gray or black, massive	26.8	58.7	1 8
	Limestone, cherty			8
97-F	Phosphate, dark gray, massive, calcareous	28.7	62.8	1 2
	Interval concealed			71 6
98-A	*Ft. in.* Shale, brown 1 5 Phosphate, gray, oolitic 4 Shale, brown 1	23.4	51.2	2 10
98-B	Phosphate, brown, earthy material	27.8	60.3	1 7
				102 1

The foregoing sections are given as typical of the small part of the phosphatic section available for measurement, representing the beds most directly associated with the main bed. Undoubtedly there are other beds, ranging from those of higher-grade rock rich in phosphoric acid to those containing only a trace, which are not included in the partial sections detailed here. Complete measurements or samples can not be obtained from the customarily poor exposures at the outcrop. It may perhaps be assumed that the main bed prospected is the thickest bed and contains the most readily workable mass of high-grade material in the section. Many other sections were measured and samples tested, and a record of the results is shown in a graphic way on the general map (Pl. XI).

The syncline containing the phosphate broadens somewhat at Brazer Canyon, and opens out even to a greater extent south of that place, so that a considerable body of the Woodside shale is included along its axis. These strata consist of shaly limestones, weathering dark sepia-brown at the base of the section adjacent to the Park City rocks, and conspicuous bright-crimson and vermilion-red shale in the upper beds of this same section at the very axis of this fold. A stratigraphic interval of about 600 feet of beds overlying the Park City formation is represented on the axis of this syncline in the lower part of Brazer Canyon.

T. 11 N., R. 7 E.

The structures carrying the phosphate beds extend into secs. 24, 25, and 36, T. 11 N., R. 7 E., as shown on Plate XI. As this part of the field is more or less remote from present shipping facilities, only shallow prospects have been dug to hold the claims, but the main bed prospected shows notable resemblance to that at the Arikaree and Mandan mines and to other sections measured between them and this end of the field.

T. 10 N., R. 7 E.

A considerable area of undeveloped phosphate land is situated in T. 10 N., R. 7 E. Some claims appear to have been staked in secs. 1 and 12, but so far as known the other outcrops shown on the accompanying map have not been located and it is believed that their existence has not heretofore been recognized.

The structure of the southern extension of the Crawford Mountains is essentially that of a simple anticline. On the west of this fold a remnant patch including the phosphate beds is still preserved in the NE. ¼ sec. 23. The beds are capped by the overlying cherty-limestone ledge and evidently owe their preservation to it. The outcrop of the phosphate beds that has been traced to the south end of the mountains at the eastern foot is evidently that of the east flank of the anticline, which is generally steep and in part overturned. The outcrop on the west flank is concealed in the valley bottoms if present.

No attempt was made to prospect this outcrop. Samples of float picked up at several places show the presence of high-grade material, and workable beds similar to those prospected farther north are probably present.

T. 9 N., R. 7 E.

The southernmost extremity of the Crawford Mountains reaches into secs. 1, 2, 11, and 12, T. 9 N., R. 7 E., and the phosphate beds have been identified as far south as the NW. ¼ NW. ¼ sec. 12. There seems little doubt that the outcrop would be continuous for a considerable distance beyond that point were it not for the erosion and alluvial fill in the Bear River valley. No examination has been made south of Bear River, and the older rocks there are believed to be masked by the cover of Eocene strata.

AREA AND TONNAGE.

Only the most general estimates have been attempted of the area or tonnage of available phosphate in the Crawford Mountains. The area included within the outcrops of the phosphate beds north of Rex Peak is approximately 1,860 acres. Rather rough estimates of area being made for the lands in the southern half of the range, a total of about 2,800 acres, or 4.4 square miles, is given as comprising the known phosphate land of the Crawford Mountains.

The tonnage estimates given here are based on the known linear extent of the phosphate outcrop. There are, so far as known, 113,000 feet of outcrop of the phosphatic strata in the Crawford Mountains. In all parts of the area these beds probably do not pass to a depth of 2,000 feet and in places perhaps not even to 1,000 feet—as, for example, in the narrower or shallower parts of the northern syncline; but there are also places where the bed is probably available to a greater depth than 2,000 feet from the outcrop, and for the purpose of general estimates the depth of the available beds below the outcrop is assumed to be 2,000 feet. If the beds are vertical, this assumes that it is possible to mine to the depth of 2,000 feet, which is not unreasonable. Based on the foregoing premises, and considering only a single 5-foot bed of phosphate from the much larger series of beds known to exist, this estimate gives a total of 90,000,000 tons of 2,240 pounds of available rock phosphate of 70 per cent grade or over in bone phosphate for the Crawford Mountain area.

LAKETOWN DISTRICT.

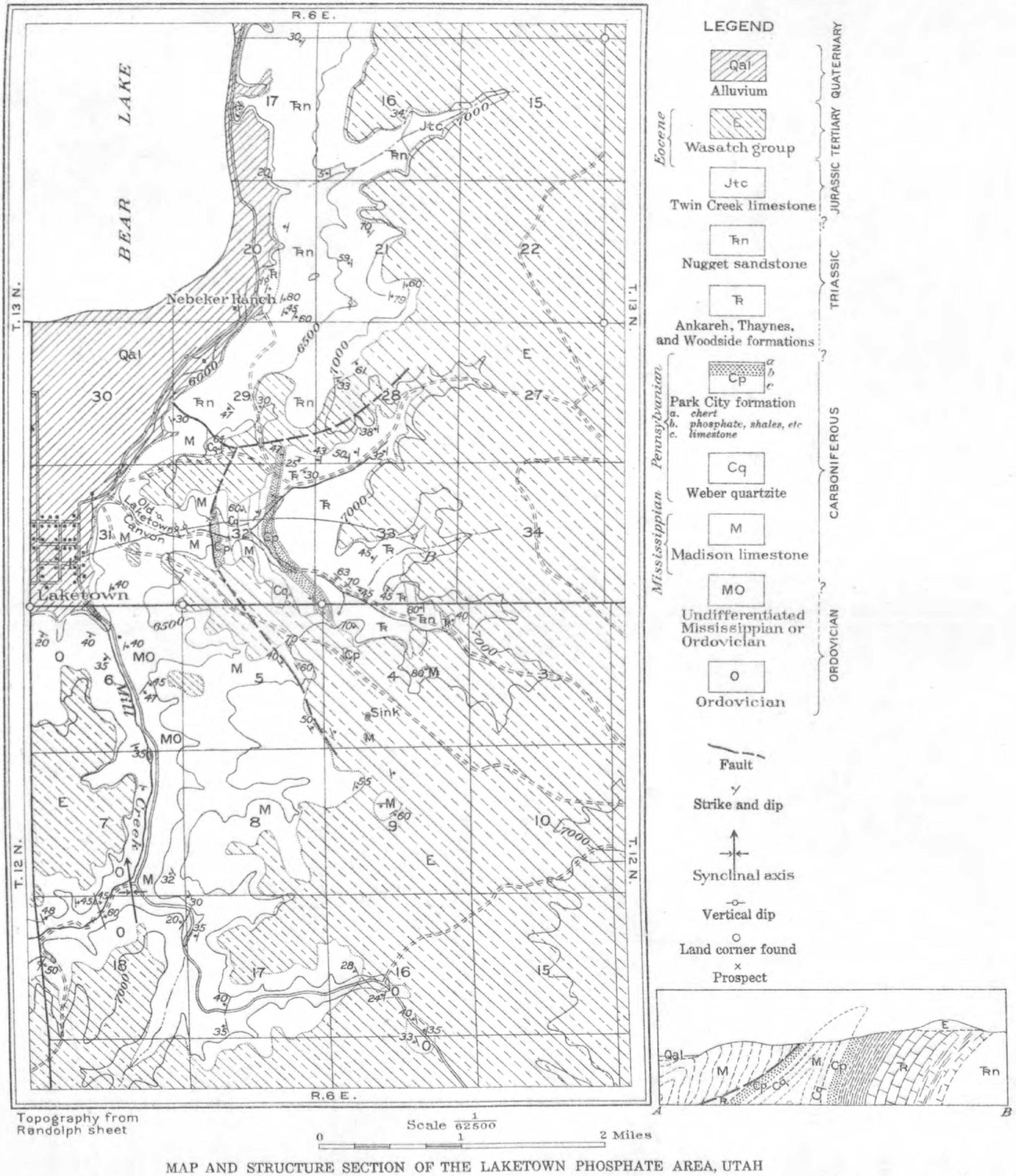
GENERAL STATEMENT.

The Laketown area, Utah, is located at the south end of Bear Lake and the phosphate deposits occur about a mile east of the town. (See Pl. XII.) At the present time the district is without adequate transportation facilities. Sage, Wyo., the nearest shipping point, in about 20 miles distant over the Bear Lake Plateau, and the cost of hauling the phosphate rock to that station would doubtless prove prohibitive on account of heavy grades, if not on account of the distance. It is possible, however, that shipment in shallow-draft barges could be made to Montpelier or to Dingle, Idaho, by way of the lake and Bear River. Transportation by water would, of course, be possible only during the summer months. Another and possibly a better solution of the problem would be accomplished by the construction of a railway along the west shore of the lake between Laketown and Montpelier. The phosphate deposits of this area are of relatively minor extent, but contain rock of excellent grade.

GEOLOGY.

The eastern portion of the area is thickly covered by the conglomerates, sandstones, and limestones of the Wasatch group (Eocene) These have, however, been removed in places, chiefly along drainage channels, and a complex of older rocks which range in age from Ordovician to Jurassic has been exposed.

The Laketown area is the only district in which any attempt was made to study the rocks older than the Mississippian limestones, as it afforded the most favorable opportunity to observe that part of the stratigraphic section. Cambrian quartzites, limestones, and shales occur to the west of Laketown and are extensively developed in the mountain range on the west side of Bear Lake, continuing northward



MAP AND STRUCTURE SECTION OF THE LAKETOWN PHOSPHATE AREA, UTAH to Paris Peak and beyond, and southward into the Monte Cristo divide. No Cambrian rocks are known at the surface east of the Bear River Range as far as eastern Uinta County, Wyo., near Labarge Mountain. Fossiliferous Ordovician rocks composed of limestones with some quartzitic bands and including some flat-pebble limestone conglomerates supposed to be characteristic of these beds are well represented west of the main canyon south of Laketown and also in sec. 16, T. 12 N., R. 6 E., where small patches of limestone are exposed along the road. Between the localities mentioned a deep syncline probably exists, the axis of which approximately follows the lower canyon south of Laketown and is occupied by rocks of the Mississippian series. The interval between the Ordovician rocks and the definitely recognizable fossiliferous Madison limestone (Mississippian) comprises several hundred feet of alternating light-colored sandy limestones and quartzite which may prove to be Silurian and includes a heavy-bedded limestone, weathering dark or black, which may represent the black Devonian limestone of the Wasatch Mountains. In the hasty examination of these supposedly Silurian and Devonian rocks no fossils were observed.

The Weber quartzite does not outcrop conspicuously in the district, but is estimated to be represented by not more than 300 feet of strata. The Park City formation is present and shows a normal succession of siliceous limestones overlain by a series of phosphate-bearing beds, succeeded in turn by the cherty limestones, as in the typical section elsewhere described.

The phosphate-bearing rocks are exposed on both flanks of a closely compressed anticline, having a north-south axis, which crosses Old Laketown Canyon a little over a mile east of the town. The lower part of this canyon is cut in Madison and possibly also older limestones which are faulted against the Park City formation, including the phosphate beds. The fault is well shown at the Austin-Wilcox phosphate claims, where Mississippian fossils occur in the ledges that are in direct contact with the phosphate beds exposed. In passing eastward up Laketown Canyon from these claims one crosses the anticlinal axis, in which Madison limestone and some calcareous Weber quartzite are exposed, and finds on the east flank of that structure the principal or more valuable outcrop of the phosphate beds. In this flank the beds are all overturned to the east, so that the strata are in inverted order, with westerly dips. East of the Park City strata are the younger formations—Woodside, Thaynes, and Ankareh—and the Nugget is extensively developed on the higher ridges. Owing to the overturned structure, the phosphate probably reaches inaccessible depths east of the outcrop. Eastward or normal dips are resumed in the surface strata in the NE. $\frac{1}{4}$ sec. 4, T. 12 N., R. 6 E.

The Woodside shale, Thaynes limestone, and Ankareh shale occur in the area and are mapped for the purposes of the present report as undifferentiated Triassic.

The Nugget sandstone outcrops in the series of rugged hills along the east side of Bear Lake and is conspicuous because of its reddish coloring. However, although this formation is composed mainly of reddish sandstones, it contains some uncolored sandstones in its upper portion.

The only outcrop of the Twin Creek limestone seen in the area is in sec. 16, but undoubtedly considerable areas of these Jurassic beds are concealed by the Tertiary cover in secs. 22, 27, and 34, T. 13 N., and probably in sec. 3, T. 12 N.

The Tertiary deposits are made up of the typical red iron-stained conglomerates, sandstones, and buff and white limestones of concretionary texture, which range from finely oolitic to coarse nodular. In places these concretionary limestones were seen to grade into and include limestone conglomerates in a manner which strongly suggests that they are of littoral origin.

The alluvial deposits consist of soils and gravels which have been derived from the areas drained by the canyons that open toward the lake and reworked along the lake shores.

The geologic structures revealing the phosphate beds in Old Laketown Canyon are terminated to the north by an east-west fault zone. This is presumably identified as a distinct fault in the ridges south of the Aquila Nebeker ranch, where the red Nugget sandstone is offset into contact with older Paleozoic limestones near the middle of the west side of sec. 29, T. 13 N., R. 6 E. North of this transverse fault zone the rocks exposed are the Twin Creek and Nugget formations, which are folded in a complex traceable northward into the Hot Springs area, near the north end of the lake. The upper limestones of the Thaynes and the mottled maroon and greenish shaly strata of the Ankareh outcrop in the crest of an anticlinal fold just east of the dwelling on the Nebeker ranch. The phosphate beds are probably about 3,000 feet deep at that place, but they dip to greater depths on both the east and the west of the anticlinal axis.

PHOSPHATE BEDS AND ASSOCIATED STRATA.

East of the overthrust Mississippian limestone in Old Laketown Canyon the Park City formation outcrops on both flanks of the compressed and overturned anticline described above. The western exposure is but partial, however, on account of the shearing produced by the overthrust, and the eastern outcrop shows a section which would be easily recognized as typical after study of the several sections illustrated on Plate IV. The cherty limestone, here comprising the upper 80 to 100 feet of the formation, weathers into bright-yellow splintery fragments.

Little prospecting has been done in the phosphate beds of this district. The only area recognized prior to 1909 was the small patch of much crushed phosphate on the western outcrop in direct contact with overthrust Mississippian limestone. Two shallow pits had been opened in the SE. ¼ NW. ¼ sec. 32. It was locally reported that these openings when made (1907) showed a 2-foot bed of high-grade phosphate rock averaging 36.6 per cent of P_2O_5, or 80 per cent of $Ca_3(PO_4)_2$, and 40 feet of material averaging 13.7 per cent of P_2O_5, or 30 per cent of $Ca_3(PO_4)_2$. A sample taken represented a 9-inch face of the richest-appearing material lying next to the fault. This sample doubtless does not represent the full thickness of the original bed, but when analyzed was found to contain 31.8 per cent of P_2O_5, or 69.6 per cent of $Ca_3(PO_4)_2$. The other prospect is in the underlying dark-colored thin-bedded shales, whose phosphatic content can be assumed with a fair degree of certainty to fall between 30 and 50 per cent of $Ca_3(PO_4)_2$.

The existence of the phosphatic shales farther up the canyon and on the eastern flank of the anticline was discovered by the Geological Survey party, and float phosphate rock collected from the surface was found to contain 34.3 per cent of P_2O_5, or 75.4 per cent of $Ca_3(PO_4)_2$. The location of a bed of high-grade rock which was regarded as the principal bed was determined and the outcrop trenched and sampled as follows:

Section of phosphate rock in sec. 32, T. 13 N., R. 6 E.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
134-A	Cherty limestone, phosphate rock, gray, coarse to medium, oolitic.	36.3	79.5	1	5
	Shale, brown	....	....		4
134-B	Phosphate rock, gray, coarse, oolitic, friable	37.3	81.7		5
134-C	Phosphate rock, gray, fine, oolitic	26.4	57.0		5
134-D	Phosphate rock, gray, coarse, oolitic, weathers into flat concretions up to 1 inch in diameter	36.7	80.4		6
134-E	Phosphate rock, fine grained, oolitic, weathered	26.0	56.5		8
134-F	Phosphate rock, gray, fine to medium, oolitic	34.1	74.7	2	10
				6	7

The total thickness of phosphate rock represented in this section, exclusive of the unsampled 4-inch parting at the top, is 6 feet 3 inches, and the average phosphate content is about 33 per cent of P_2O_5, or 73 per cent of $Ca_3(PO_4)_2$. The presence of soil introduced into the many minute joints in the phosphate rock has probably caused the results to fall below the normal amounts that would be obtained in samples taken farther in on the bed. The quality of this phosphate rock compares well with that of the rock seen in the main beds of the other districts and is up to the standard of ore considered minable by the phosphate companies operating in the western fields at the present time. The presence of other beds of high-grade phosphate rock and the amount or character of the low-grade material have not been determined. It is suspected that a complete section of the beds would correspond closely with that part of the section measured and sampled at Hot Springs, Idaho (p. 497) and in general would be comparable with the section of the entire series of phosphate beds represented on Plate IV.

AREA AND TONNAGE.

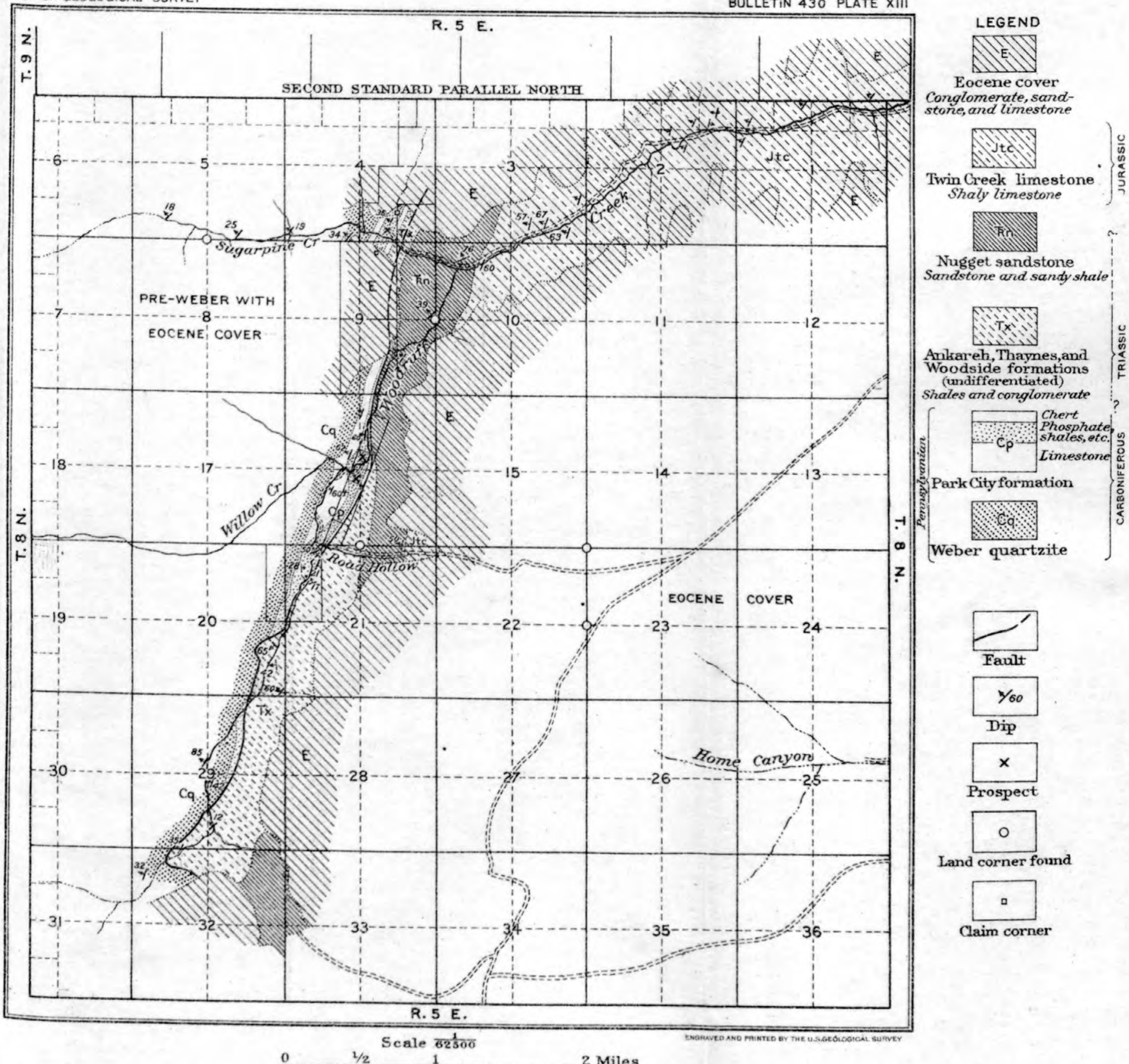
In computing the area and tonnage of all rock present in the high-grade bed the outcrop on the eastern flank of the anticline is alone considered, the western outcrop being rejected because of doubt as to its presence or value beyond the meager exposures in Old Laketown Canyon. The length of the eastern outcrop exposed between the boundaries of the Tertiary cover on the north and south flanks of the canyon is about 1.3 miles, or approximately 7,000 feet. A depth along the bed of 2,000 feet is assumed to be minable. On the basis of a 6-foot bed the estimate obtained is, in round numbers, 6,750,000 tons of 2,240 pounds for the Laketown area. This figure must be regarded as conservative, but no data exist from which a satisfactory conclusion can be obtained as to the amount of the phosphatic values contained in the remainder of the section. It is fairly certain, however, that the main body of phosphatic shales will, as in the other areas, in time prove of at least equivalent value to that of the content of the bed discussed above, especially if the agricultural use of 40 to 60 per cent raw phosphate shall become general.

However, under present conditions of transportation the Laketown deposits must be considered as a reserve rather than as deposits in which developments are to be expected in the near future.

WOODRUFF CREEK AREA, UTAH.

LOCATION AND DEVELOPMENT.

The phosphate deposits usually referred to as the Woodruff Creek area are situated on Woodruff or Twelvemile Creek and on a fork of the latter known as Sugar Pine Creek, in Rich County, Utah. (See Pl. XIII.) The developments are about 14 miles, in a direction somewhat south of west from the town of Woodruff. The openings on the phosphate beds are limited to a few pits and drifts, all of which were badly caved at the time of the present examination. The Woodruff Creek area compares rather unfavorably with most of the other districts described in this report, especially in two respects—transportation facilities and the geologic conditions affecting that part of the Park City formation which carries the phosphate. A



GEOLOGIC MAP OF PHOSPHATE DEPOSITS NEAR WOODRUFF, UTAH wagon road has been constructed by the San Francisco Chemical Company as part of the assessment work incident to holding the phosphate claims. The development work on the claims themselves appears to have been perfunctory, with the idea of meeting the requirements of the mining law rather than of proving the extent and character of the deposits. Water grades down Woodruff Creek and thence following the Bear River valley offer feasible railroad routes, should it become desirable to reach this property in that way.

GENERAL GEOLOGY.

The outcrops of the rocks immediately related to the phosphate deposits are limited to the bottoms of the deep canyons which have been cut by Woodruff or Twelvemile and Sugar Pine creeks through the Eocene cover, comprising at least 1,000 feet of the overlapping limestones and conglomerates of the Wasatch group. The general structure of the whole area is that of a completely overturned sequence, from the older Paleozoic rocks to the Jurassic. The area is presumably at the eastern margin of the major anticline of the Monte Cristo divide. The whole attitude of the rocks is expressive of a strong compressive force originating west of this area and acting toward the east; it is in conformity with and is probably a direct continuation of the similar structure on the west shore of Bear Lake and north of that region. The Woodruff Creek area is also regarded as the west flank of a recumbent syncline having a nearly northeast axis which may be recognized in the section on Woodruff Creek below the phosphate outcrops.

These rocks are faulted by overthrusts from the west. A fault zone may be traced from north to south, evidently developed throughout chiefly along the weaker shaly members of the Park City and Woodside formations. On Sugar Pine Creek the combined Woodside, Thaynes, and Ankareh formations appear abnormally thin, owing to the telescoping action of the fault zone included at this place within their boundaries. Definite evidence of the existence of the fault is seen immediately above that part of Twelvemile Canyon lying in the Nugget sandstone, where the phosphate-bearing shales of the Park City formation are found close to the Nugget. In secs. 21 and 28, T. 8 N., R. 5 E., the phosphatic shales lie in contact with the Woodside shale, the normally interstratified *Productus*-bearing cherty limestone characteristic of the upper portion of the Park City formation being absent. The Weber quartzite in secs. 20 and 29 was observed in contact with beds supposed to belong to the Lower Triassic. The existence of the fault zone is further indicated by observed minor faults, mashing, brecciation, and slickensides in various places along Twelvemile Creek in secs 16, 20, 21, and 29, and south of the mouth of Road Hollow slumping and readjustment are indicated by the disturbed condition of the phosphate shales.

The existence of a fault zone of this kind and magnitude has a marked economic bearing on the value of the phosphate deposits of this area, as it serves both to reduce the amount of available phosphate and to render difficult the mining of that portion of the deposits which may possibly be regarded as available.

PHOSPHATE AND ASSOCIATED ROCK STRATA.

The Park City formation is best exposed in this district in sec. 4, T. 8 N., R. 5 E., and so far as noted shows nearly the normal succession of beds as found elsewhere. It is limited at its base by a series of sandy limestones and at its top by the cherty limestones bearing *Productus* and *Spiriferina*. West of the outcrop of the Weber quartzite the rocks noted are composed of quartzites and metamorphosed conglomerates of probably pre-Weber age. Their age or relation to the Weber quartzite were not determined. Rocks of Carboniferous age are not known to outcrop in the township other than as shown on the accompanying map (Pl. XIII). The overlying formations, except where faulted, are thought to be present in nearly normal sequence.

The prospect in the SW. ¼ SE. ¼ sec. 4, on the Colbert placer claim, was caved and no measurements were obtained at the time of this examination. It is reported that the bed exposed in this opening measured 5 feet and was composed of high-grade phosphate rock. A 5-foot bed of similar quality is also said to have been exposed in an open cut found by the present survey to be in the northwest corner of the Seymour placer claim, or the SE. ¼ SE. ¼ sec. 4.

The prospects in secs. 16 and 21 were also so badly caved that it was impossible to obtain satisfactory measurements of the phosphate rock or to collect representative samples for analysis. A sample was taken from an old entry in the SW. ¼ SE. ¼ sec. 16, representing 2 feet of brownish-black shale which contained 12.2 per cent of P_2O_5, equivalent to 26.5 per cent of $Ca_3(PO_4)_2$. Brown oolitic phosphate rock collected at random from the dump of a caved prospect in the NE. ¼ SW. ¼ sec. 16 yielded better results—23.7 per cent of phosphoric acid, equivalent to 51.9 per cent of bone phosphate. A trench in the SE. ¼ SW. ¼ sec. 16 showed about a 5-foot face of rather coarsely oolitic material which has been reported to contain from 30 to 32 per cent of P_2O_5, which is equivalent to 65.5 to 69.9 per cent of $Ca_3(PO_4)_2$.

A caved tunnel and a stripping in the NW. ¼ NW. ¼ sec. 21 exposed somewhat less than 60 feet of the phosphate series. An analysis of a selected sample taken from the outcrop at this point contained only 15.2 per cent of P_2O_5, or 33.3 per cent of $Ca_3(PO_4)_2$.

AREA AND TONNAGE.

The area underlain by phosphate in this district can be determined only by extensive and presumably costly prospecting. At present no basis exists for a satisfactory estimate of the tonnage. It is doubtful, however, if thorough prospecting will be considered warranted under the present conditions of accessibility and uncertain value of the deposits. It seems that the Woodruff area, although, as reported, one of the first discovered, will probably be among the last to undergo extensive economic development.

SUMMARY.

TONNAGE OF THE AREAS EXAMINED.

As has been stated, the districts now recognized as containing phosphate deposits of commercial availability have been by no means completely reviewed in the foregoing detailed consideration, for this report is of preliminary character and covers only the results of the last season's field work. The estimates of area and tonnage given are, of course, approximate at best, but they are derived from the most complete data available at the present time. Emphasis should be placed on the fact that all these estimates are based to a considerable extent on arbitrary assumptions, all of which, however, are carefully explained in the text accompanying the statements. All the estimates made are intended to be amply conservative.

Of the assumptions on which the tonnage estimates are based, the most arbitrary and probably the most deficient in expressing a just estimate of the field is that which takes into account only a single 5 to 6 foot bed of phosphate rock as workable and available throughout the known extent of these areas. The review of the detailed sections shows how vastly greater than the result so obtained the actual total phosphoric acid content of these rocks must be. At the present time, however, only rock equivalent on the average to 70 per cent or more of tricalcium phosphate is considered shipping ore, and of this material there is usually to be found in a single section only one bed that attains a thickness of 5 feet or more. For this reason any particular locality usually has what is referred to as its "main bed." A glance at the generalized columnar sections given in Plate IV shows that in fact high-grade rock phosphate occurs in at least two major horizons in the phosphatic section, of which the "main bed" appears to be an upper or a lower member, according to minor local variations. An attempt to compute accurately the vast tonnage of intermediate and low-grade phosphatic material involves numerous additional arbitrary assumptions, several of which would at present be based on evidence so insufficient or incomplete as to make them of little value.

The figures presented are thus chiefly of value as expressing a minimum and, with little doubt, an exceedingly conservative estimate and for comparison among the various areas they are repeated in summary form below. It should be distinctly understood that they represent but part of the entire field:

Tonnage estimates of phosphate rock available in the various areas reviewed in this report.

	Long tons.
Georgetown area	90,000,000
Montpelier-Bennington area	16,000,000
Hot Springs-Dingle area	27,000,000
Sublette Mountain area	32,000,000
Cokeville area	2,400,000
Beckwith Hills area	2,800,000
Crawford Mountain area	90,000,000
Laketown area	6,750,000
Woodruff Creek area (not estimated).	
	266,950,000

RELATIONS OF THE OGDEN AND WEBER RIVER AREAS.

The report on the examination of the phosphate deposits east of Ogden, Utah, by Eliot Blackwelder forms the succeeding paper in this volume. Comparison with the results of that work seems to indicate that the rock-phosphate deposits decrease in thickness and relative value or richness in phosphoric acid toward the south. Analyses of rock from the localities near Salt Lake City, south of the Ogden and Weber River areas, though they may not be representative of the best material and do not give any indication of the amount of ore available, seem to show a relatively lower content of phosphoric acid in that general direction. Reports from these localities persistently state that even the better beds are relatively thin where found, 12 to 24 inches being the usual thickness given. From the sections detailed in the report on the Ogden and Weber areas, there appears to be at one locality a 13-foot bed showing an average content of phosphoric acid equivalent to 46.1 per cent of tricalcium phosphate, and the report also refers to beds exposed at other localities which average from 39 to 62 per cent of tricalcium phosphate. Of the analyses obtained only those of residual fragments or "float" have shown a composition comparable with that of the better material of the larger fields to the north.

SIGNIFICANCE OF WORK DONE AS TO TOTAL EXTENT OF DEPOSITS.

The continuity of the deposits within the area already examined is a good indication that these beds originated under conditions of great uniformity and wide extent, both in manner of deposition and in the character of the material brought in to make up the strata. Continuity of the rock formations with which the phosphate is identified throughout the area of lands withdrawn in the phosphate reserve (see fig. 41) is well established in a general way. The actual commercial availability of phosphate deposits beyond the areas now known can be determined only by examination and study. Such scattering evidence bearing on this subject as has been brought together seems to indicate the great probability that the deposits are at least as extensive as the first predictions implied, and it is well within the limits of possibilty that these western fields may prove to be as extensive as any of the other known fields of the world.

AVAILABILITY OF LOW-GRADE PHOSPHATES.

In the tonnage summaries of the several districts brief references have been made to the possibilities of future use of the low-grade phosphate-bearing rocks, and a statement in review of the entire field may serve to emphasize the importance of this phase of the subject. Throughout the areas covered by the present tonnage estimates of high-grade rock, the phosphatic portion of the Park City formation contains in addition at least 40 feet of phosphatic shales, averaging perhaps 18 per cent of P_2O_5, equivalent to about 40 per cent of $Ca_3(PO_4)_2$, or, in round numbers, 2,000,000,000 tons of low-grade rock. The problem of utilizing such material, in either a raw or a mixed state, is one of importance, with regard not only to the deposits here discussed, but also to those in certain of the eastern fields—notably Florida, where large quantities of low-grade and even some high-grade rock are discarded at present. The phosphatic shales of the western fields can be cheaply mined and cheaply ground and apparently in their natural condition contain organic substances which, when subjected to soil-weathering conditions, tend to gradually render their phosphoric acid content available either as a plant food, as a neutralizer of soil toxins, or otherwise. Experimental and practical applications of ground phosphate (phosphate meal or floats) are reported to be successful to a certain extent in this country and also in France and Russia. Furthermore, the exponents of this system of soil treatment maintain that it is free of the evils attendant on the use of superphosphates—namely, a tendency toward excessive acidity and the accumulation of harmful or injurious sulphates. The question is raised whether the future treatment of the soils of this country as a whole, or at least in part, may not lie in the direction of utilizing the natural phosphates rather than in the sole use of the high-grade material in the form of superphosphates.

NEED OF REVISION IN THE MINING LAW AS APPLIED TO PHOSPHATE LANDS.

Provisions in mining law for method of locating phosphate claims.—When the existence of valuable deposits of rock phosphate in the public lands in Idaho, Utah, and Wyoming was discovered about five years ago, an interesting question in the application of the American mining law was brought forward. In the establishment of the mining law and its subsequent enactments and provisos and the development of regulations thereunder the subject of rock-phosphate deposits had never been specifically taken into consideration. Prior to the granting of the first patent as placer land in the Idaho phosphate fields all entries for lands embracing phosphate deposits had related to placer locations. Phosphate deposits of a true placer type exist and form a most valuable part of the Florida and South Carolina fields, but the rock-phosphate deposits of Idaho, Utah, and Wyoming are undoubtedly more properly analogous to coal than to either of the types of mineral deposits specified in the other mining laws. When the western phosphate deposits were discovered and the lands came to be staked and claimed in mineral locations, no recognized precedent had been established as to the proper form of entry upon such lands.

Character of western phosphate deposits.—A study of the phosphate beds of the Idaho, Utah, and Wyoming fields, and of the relation of the ores to the series of stratified rocks within which they are interbedded, shows them to be original sedimentary deposits. The phosphate rocks are part of the great series of sedimentary strata, deposited under water at a time when this region was largely submerged. Since the deposition of these beds other deposits have accumulated in a similar manner to a thickness of many thousands of feet, and deformation of the earth's crust has folded and broken the originally flat-lying strata. Thus the rock-phosphate ores are far more similar in the manner of their occurrence and origin to such deposits as coal, sandstone, and limestone, and especially to the Clinton iron ores of the Appalachian region, than they are to the ore deposits formed in veins, lodes, shoots, or to alluvial deposits of the placer type.

Mineral claims as defined by law.—Except for coal lands, mining claims as defined by the laws may be of two classes—placer and lode claims. A lode claim as prescribed is a parallelogram 1,500 feet in length along the course of the mineral vein or lode and of a width not to exceed 300 feet on either side of the vein or lode at the surface. No strict definition of the terms "vein" or "lode" is given, but one is implied (sections 2320 and 2329, Rev. Stat.) where deposits of this class are referred to as "bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits," and placers as "including all forms of deposit, excepting veins of quartz or other rock in place." The placer law provides for the sale of not more than 20 acres of land to any individual, but fixes the price at $2.50 an acre, which is half that of the lode claim. The privileges acquired in a lode claim include, however, what are known as extralateral rights. Other requirements for acquirement of title to the land are essentially equivalent in the two forms of entry.

Since the establishment of the lode and placer laws, and aside from that relating to coal lands, separate enactments of Congress have authorized the application of the provisions of the placer-mining law, first to lands chiefly valuable for building stone and later to lands containing petroleum or other mineral oils and chiefly valuable therefor. Still a third enactment has extended the placer form of entry to deposits of salt in any form. Thus exception to the definition of a lode deposit as necessarily "rock in place" is officially recognized.

Western phosphate deposits not strictly of lode or placer type.—Owing to the precedent that had been established from the first placer locations that had been granted in Florida, it was at first assumed that phosphate lands in Idaho should also be located under the placer proviso of the mining laws. In both the legal and the geologic meaning of the term, the Idaho rock-phosphate deposits are certainly "rock in place." They are analogous to most sedimentary building-stone deposits in the manner of their formation, but like coal they are also bodies of valuable mineral inclosed between walls. According to the scientific or geologic definitions, these deposits are not properly lodes or veins. In any sense, however, the western phosphate deposits do not conform to the placer type, and unless by specific act of Congress it appears that there is so far no sufficient warrant for their location under the placer law.

Court decisions have not always upheld the strict or scientific definition of the term "vein" (or lode used in the same sense as vein), and there is, therefore, reasonable doubt as to the applicability or nonapplicability of that term in its legal sense to these phosphate deposits. Undoubtedly they are not veins or fissure fillings according to the accepted mineralogical or geologic definitions. The so-called popular mining use of the terms vein and lode very probably originated in large part through necessities arising from the inapplicability of the mining law. Loose interpretation has been forced in the effort to stretch the provisos of the law to cover conditions not provided for. Certain legal authorities—perhaps a majority—may be quoted as entirely in favor of a loose popular interpretation of the term "lode," so that bedded sedimentary rocks would also fall within that class.[a] However justified this may be for the present status under the law, or however well substantiated in court decisions, the fact remains that it is incongruous and illogical and points to the need for special consideration by Congress.

[a] Lindley, C. H., A treatise on the American law relating to mines and mineral lands, 2d ed., vol. 1, 1903 (footnote under 290a), p. 510, and other references.

Titles granted in western phosphate fields.—Title has passed in two cases in the western phosphate lands—the Waterloo claim at Montpelier, Idaho, and the Bradley group of claims in the Crawford Mountains, Utah. The Waterloo patent was granted as a placer and the Bradley claims were later allowed to patent as lodes. As previously stated, prior to the granting of the Waterloo patent all entries for phosphate lands were made in the Florida field and presumably covered deposits of the true placer type, and it appears that the distinction between those deposits and the phosphate beds of western fields was perhaps not clearly brought out at that time. Under a strict interpretation of the present law, with a recognition of the true character of the western deposits, it may be held in the courts that they must be considered as covered by the lode law. It is to be hoped, however, that further patents in these western fields may be withheld until an equitable adjustment of the existing difficulties can be provided.

Extralateral rights.—The most serious objection to the application of the lode law to the western rock phosphate fields is the interpretation thereby placed on the so-called extralateral rights. A recognition of the inapplicability of this proviso in the case of coal lands was early brought out by the necessity for providing for their disposition. On account of the bedded character of the phosphate deposits and the great uniformity of the beds throughout wide areas, in the strata with which they occur, there is not the uncertainty as to their continuity in depth that prevails with respect to typical mineral lodes or veins in the stricter definition of the terms. Under the application of this proviso of the law title would be granted not only to the outcrop of the phosphate but also to the beds in depth as far as they continue to dip, even if the dip is but very slight. This would enable the locator of a single lode to extend his extralateral rights for long distances, even for a number of miles in regions where the rocks continue to dip for that distance. It is perfectly obvious that such methods of disposition can not be contemplated as a proper administration of the public lands.

Injustice of present law to individuals and communities.—The possibility for contest and legal controversy over the form in which original locations had been made in the phosphate fields was early recognized. Most of the first entries were made as placer claims; many of the original placer claims were later relocated as lodes, as a rule by other persons than the first holders. This relocation is said to have been done surreptitiously, so that it constituted in effect claim "jumping." Original locators had proceeded in apparent good faith to survey, develop, and improve the property to which they were seemingly entitled. The opportunity for contest and litigation has been seized, and almost invariably double locations are now made along the outcrops in the most accessible parts of the fields, double assessment work is done, and other unwarranted expenses are being incurred. Aside from the injustice to the individuals concerned, this procedure is an economic waste, to be ultimately paid for by the consumer and the general public. The burden thus imposed on the development of the phosphate lands is in direct contradiction of the policy of encouragement of mining industries, is an obvious hindrance to the honorable exploitation of these valuable deposits, and by reaction on the community constitutes a general repression of the possible industrial advancement.

Assessment work unnecessary and wasteful.—Whatever the advantage of the proviso in the law requiring annual improvement or assessment work on both placer and lode claims, existing conditions observed in the phosphate fields indicate that such work is certainly unnecessary and wasteful as applied to phosphate lands. A moderate amount of development is usually necessary to fully reveal the character, value, or extent of the deposit on any claim, but the requirement of an annual expenditure of $100 on each claim, or its equivalent for a group of claims, is, in almost every case where actual commercial operation of the property is not commenced, exorbitant and wasteful, both in itself and in its practical application.

Present status of phosphate lands.—At the present time all public lands known or supposed on good evidence to contain valuable phosphate deposits are withdrawn, by an order of the Secretary of the Interior, from all forms of entry under the public-land laws. These withdrawals are only temporary, as they are intended to prevent further entanglements and to preserve the present status of the lands until appropriate action shall be taken by Congress.

PHOSPHATE DEPOSITS EAST OF OGDEN, UTAH.

By Eliot Blackwelder.

INTRODUCTION.

The most important known deposits of lime phosphate still belonging to the Government are scattered through northern Utah, southeastern Idaho, and southwestern Wyoming. This field was reconnoitered several years ago by F. B. Weeks,[a] who visited the previously known localities. In 1909 the larger part of the field was surveyed by a party in charge of Hoyt S. Gale, whose report appears elsewhere in this volume, and the deposits in a relatively small area in the Wasatch Mountains east of Ogden, Utah, were investigated by the present writer, assisted by J. M. Jessup and M. A. Becher.

GEOGRAPHY.

The phosphate deposits here considered are situated in Weber and Morgan counties, Utah, in the drainage basins of Weber and Ogden rivers. (See fig. 44.) Topographically the district includes two ranges of mountains imperfectly separated by a chain of intermontane basins. The western range is the one usually called the Wasatch Mountains. That on the east is the southward extension of the Bear River Range or Plateau. The western range is considerably higher, narrower, and more rugged than the eastern range, which is plateau-like, but deeply dissected by canyons. The Morgan and Huntsville basins, between the ranges, are broad and flat-bottomed and are thoroughly cultivated.

The hilly and mountainous parts of the district were once forested but are now largely denuded of timber. They are, however, well covered with tough oak brush on the higher slopes and sage on the lower slopes. The two rivers and their principal branches are permanent streams, but many of the smaller canyons are dry most of the year. Wherever there is soil and water for irrigation the land is under cultivation. The mountains are used as range for bands of sheep, which keep the grass and flowers closely cropped.

[a] Bull. U. S. Geol. Survey No. 315, 1907, pp. 449-462; No. 340, 1908, pp. 441-447.

The Union Pacific Railroad crosses the district from east to west, and several railroads run north and south along the west base of the Wasatch Range. Good wagon roads lead into the Huntsville and Morgan basins, but in the mountains roads worthy the name are scarce, and many of the canyons are quite impassable for vehicles.

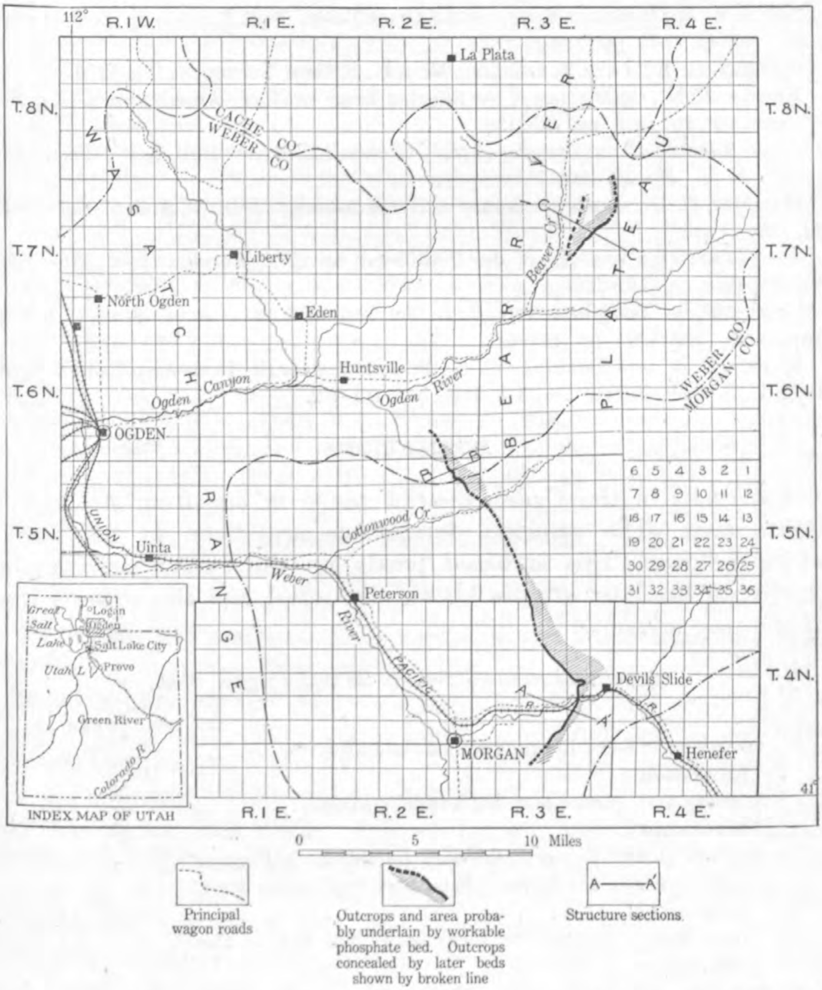


FIGURE 44.—Map showing distribution of phosphate deposits near Ogden, Utah. By Eliot Blackwelder.

GENERAL GEOLOGY.

PREVIOUS REPORTS.

The geology of this district is described in the reports of the Hayden Survey and the Fortieth Parallel Survey of the sixties and seventies. Since that time only papers on special subjects, most of them brief, have been published. A list of the more important of these papers follows:

ATWOOD, W. W., Glaciation in the Uinta and Wasatch mountains: Prof. Paper U. S. Geol. Survey No. 61, 1909.

BOUTWELL, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434–458.

DAVIS, W. M., Mountain ranges of the Great Basin: Bull. Mus. Comp. Zool. Harvard Coll., vol. 42, 1903, pp. 128–177.

GILBERT, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

KINDLE, E. M., Occurrence of the Silurian fauna in North America: Am. Jour. Sci., 4th ser., vol. 25, 1908, pp. 125–129.

——— Fauna and stratigraphy of the Jefferson limestone: Bull. Am. Paleontology, Ithaca, N. Y., No. 20, 1908.

WALCOTT, C. D., Cambrian faunas of North America: Bull. U. S. Geol. Survey No. 30, 1886.

——— Cambrian sections of the Cordilleran area: Smithsonian Inst., Misc. Coll., vol. 53, 1908, pp. 167–230.

WEEKS, F. B., Phosphate deposits in the western United States: Bull. U. S. Geol. Survey No. 340, 1907, pp. 441–447.

WEEKS, F. B., and FERRIER, W. F., Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 315, 1906, pp. 449–462.

FORMATIONS.

The rocks in the Ogden district range in age from Archean to Quaternary. The principal formations are given in the section which follows. This is based partly on the earlier surveys, but chiefly on the later studies above mentioned and the writer's work of the past season.

Generalized section of rocks in the Ogden region, Utah.

	Feet.
Quaternary: Lake Bonneville beds and alluvium	?
Unconformity.	
Tertiary and Quaternary: High-level gravels	?
Unconformity.	
Tertiary (lower Eocene): Wasatch formation (tuffaceous conglomerate, sandstone, shale, and fresh-water limestone)	0–3,000
Unconformity (Cretaceous rocks occur just east of this district).	
Jurassic and Triassic strata (not studied in connection with the work on the phosphate deposits)	8,000–11,000
Triassic or Carboniferous (Permian):	
Ankareh shale	1,500
Thaynes limestone	1,200
Woodside shale	1,200
Carboniferous:	
Pennsylvanian—	
Park City formation (limestone, shale, and phosphate rock)	500–1,600

Carboniferous—Continued.	
Pennsylvanian—Continued.	
Unconformity.	Feet.
Weber quartzite	0–4,000
Red beds	0–1,000
Unconformity.	
Mississippian: "Wasatch limestone" of King, in part (consists of upper fossiliferous black limestone, middle reddish and buff shale, and lower gray dolomites devoid of fossils)	4,000–5,000
Devonian: Jefferson limestone	500–1,000
Silurian limestone	100–400
Ordovician limestone, with local shale and quartzite	500–2,000
Cambrian, chiefly limestone, with beds of shale and a basal quartzite; divided by Walcott into eight formations	1,847–6,600
Unconformity.	
Algonkian (?): "Cambrian quartzite" of King (alternating quartzite, graywacke, and slate)	10,000–12,000
Unconformity (?), not observed.	
Archean, complex of schist, gneiss, etc.	

The formations of chief importance in connection with the phosphate investigations are those of Triassic (?) and Carboniferous age, including the Mississippian, Pennsylvanian, and Permian (?).

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

In this district the Mississippian series is readily divisible into three formations. At the base, intergrading with limestone probably of Devonian age, are brittle gray dolomites with thin beds of drab shale. They have furnished no fossils, and their age is estimated from their stratigraphic position. Separated from the dolomites by an obscure and probably unimportant unconformity is a shaly formation about 250 feet thick. This comprises shales, shaly limestone, thin-bedded dolomite, and soft sandstone, in which the prevailing colors are red, pink, buff, and ash-gray. Many of the strata have sun cracks, but fossils are rare or altogether lacking. The shaly formation grades upward into dark-gray and black limestones which are alternately thick and thin bedded. In these limestones middle Mississippian fossils are generally abundant. In the northern part of the district the fossiliferous limestones are succeeded by 1,000 to 2,000 feet of shales, thin-bedded limestone, chert, and sandstone containing fossils provisionally referred by Girty to the late Mississippian (Kaskaskia) horizon of the Central States. At the base of this shaly succession there is a lean phosphatic zone which appears to be of little value within this district, but may prove to be worth prospecting elsewhere.

PENNSYLVANIAN SERIES.

WEBER QUARTZITE AND UNDERLYING RED BEDS.

In the southern part of the district the Mississippian limestone and the Park City phosphatic beds are separated by the thick Weber quartzite, and the underlying red beds. At the type locality in Weber canyon the quartzite is said to be 5,000 to 6,000 feet thick, but it thins toward the north and entirely disappears within 8 miles, so that farther north the Park City formation is everywhere directly in contact with the Mississippian strata. At the base of the Weber quartzite and intergrading with it, there are red beds consisting of brick-red sandstone with some sandy shale and thin beds of cherty gray limestone. The limestones have yielded a few fossils that are closely related to those in the lower part of the Weber quartzite, and are considered by Girty to be of Pennsylvanian age. The red beds are separated from the underlying limestone by a distinct unconformity, but the testimony of the fossils seems to indicate that the interruption of deposition was brief. The Weber quartzite proper consists of creamy-white quartzite or hard sandstone interbedded, particularly in the lower part, with cherty dolomites of dark gray to black color. A characteristic of the upper beds of the quartzite is a coarse pitting of the surface which is probably due to the leaching out of calcite unevenly distributed through the formation.

PARK CITY FORMATION.

The Park City formation contains the only workable deposits of phosphate rock at present known in this district. It consists largely of black cherty limestone with beds of shale and phosphate rock. The base is generally marked by white and pink beds of soft sandstone, separated from the Weber quartzite by an obscure unconformity which appears nevertheless to be one of considerable importance. A conspicuous and persistent member of black or gray cherty limestone follows the sandstone, and upon this lie the alternating beds of shale, limestone, and phosphate rock which contain the workable deposits. The upper part of the formation consists of lighter-colored shales, drab, gray, and olive green, with thin beds of limestone. Fossils are not abundant, but those found above and within the phosphatic zone are indicative of late Pennsylvanian age.

TRIASSIC OR CARBONIFEROUS.

The Park City formation is followed by rocks which are believed to be of either Triassic or Permian age or both. In the Park City district Boutwell has divided these rocks into three formations, all of which can be recognized in the valley of Weber River. The first, the Woodside shale, consists of brick-red ripple-marked shale and thin beds of shaly limestone, passing downward gradually into the gray and greenish shale at the top of the Park City formation. The red shale is followed by the Thaynes limestone, consisting of argillaceous gray limestone and interbedded calcareous gray shale. The limestone layers contain abundant pelecypod shells. The Thaynes limestone grades upward into the Ankareh shale, which consists of red shales and thin-bedded greenish limestones, the shales being characterized here also by many ripple marks. This formation is well exposed in the railway cut just west of Devils Slide station.

STRUCTURE.

In considering the structure of the district four units need to be discriminated—(1) the Archean rocks, (2) the great series of beds ranging from Algonkian (?) to Cretaceous, (3) the Tertiary, and (4) the late Quaternary. Each of these four units has its own independent structural features.

The structure of the Archean rocks is so complex that it is as yet almost unknown. The rocks are not widely exposed in the district, and they have so little to do with the subject of this report that no further mention of them seems necessary.

The Algonkian-Paleozoic-Mesozoic sequence, which for brevity's sake may be called the folded sequence, is structurally a unit. From top to bottom the beds are almost parallel in stratification, and such differences in degree of alteration as exist are dependent more on local factors than on age. Within this sequence there are several unconformities, all of which are relatively obscure. Two of them, however, are of considerable importance—that at the base of the Cambrian and that within the Pennsylvanian. The whole sequence has been moderately folded and at the same time locally broken into slabs where there has been overthrusting. Normal faults of later date, and probably of two generations, further complicate the structure of these beds. The main Wasatch Range is essentially a monocline with moderate eastward dip, sharply cut off on the west. The western limit is generally believed to be a normal fault scarp of rather recent date. Although the simple monoclinal structure prevails from Brigham northward to the end of the range and is evident here and there farther south, the structure is far more complex in the Ogden district, chiefly because there the rocks are affected by many overthrusts. There is one master thrust which brings the Algonkian strata out over Carboniferous and all older beds. This runs from the front of the range near Willard diagonally across the mountains to the east end of lower Ogden Canyon and thence along the east base of the range to the point where it disappears beneath the alluvium near Weber River. West of and beneath this master thrust there are several other large and many smaller overthrusts.[a] Several small transverse normal faults with roughly east-west trend shift the outcrops of the monoclinal succession in the vicinity of Ogden. A very large normal fault runs from the city of Ogden east by north across the Huntsville basin and far into the Bear River Range. It shifts all the pre-Tertiary outcrops horizontally one-fourth of a mile to 3 miles.

The portion of the Bear River Range which enters this district may be separated into two divisions, the part north of the great Huntsville fault and the part south of that line. In the southern division the structure appears to be largely monoclinal with dips varying from nearly horizontal to vertical and even overturned. Except where overturned the dips are eastward, as in the main range. This monocline is by no means simple, being interrupted by at least one prominent knee-shaped fold and perhaps by two. Considered in ground plan it shows also small drag folds, the axes of which are parallel to the dip of the monocline. Most of these little folds are overturned toward the southeast. They are largely confined to the weak shaly beds and seem to be a result of slipping of the more competent strata along the bedding. On the west side of Mount Morgan there is a series of faults, apparently of the normal type. These have been traced northward almost to the Huntsville fault, but they are largely obscured by superficial gravel.

In the northern division of the Bear River Range the structure is that of a broad syncline or synclinorium, which pitches gently northward and eventually embraces Cache Valley as well as the Bear River Mountains. No faults of noteworthy dimensions have been found in this structure within the limits of the Ogden district. The sequence appears to be unbroken. On the west the great mass of Algonkian quartzites and slates is followed in turn by the entire Paleozoic succession up to and including the Park City formation with its phosphate beds. On the east limb the beds are involved in gentle minor folds, so that the Paleozoic sequence, particularly the Mississippian limestone, outcrops for many miles where it has been uncovered in the canyons. The eastern limit of the syncline is beyond the area under consideration.

The Tertiary beds were laid down upon a hilly or mountainous surface left by erosion some time after the folding and faulting of the older rocks. They are now thickest where there were Tertiary valleys, as along Beaver Creek and thence south to Devils Slide. Elsewhere they cap plateaus and ridges, where they have been left isolated by the trenching of valleys. The beds are nearly horizontal, but dips of 5° to 10° are not uncommon and some as high as 20° have been recorded. This implies that they have been slightly folded since they

[a] This structure is described in greater detail in the writer's paper "New light on the geology of the Wasatch Mountains, Utah" (Bull. Geol. Soc. America, vol. 21, 1910).

were deposited. To this nearly horizontal blanket of Tertiary beds is due the concealment of the phosphate beds in most of northern Utah.

There is a younger formation, consisting of coarse quartzite gravel and bowlders, which was probably first deposited in the Tertiary period. The gravel is strewn over the ridges and flat divides, particularly in the Bear River Plateau. It is generally found upon outcrops of the Eocene sandstone, but is not by any means confined to such situations. It was probably laid down on a higher surface in an earlier cycle of erosion; but as the valleys were cut deeper and the hills wasted away the gravel sheet has worked its way down over the slopes until it now forms a veneer of variable, but generally slight thickness.

The Quaternary sediments occupy the terraces and floors of the valleys and broad basins. They are still in their original attitude and are essentially unconsolidated.

THE PHOSPHATE DEPOSITS.

SURFACE DISTRIBUTION.

With the exception of a small patch of lean phosphate rock in lower Ogden Canyon, the known exposures of phosphate beds in the district considered in this paper are confined to the Bear River Range. They are best exposed in upper Weber Canyon, whence the outcrop has been traced several miles to the north and southwest. In the valley of Cottonwood Creek, an important tributary of Weber River, the phosphate deposits are concealed, but are doubtless present. They reappear here and there with very poor exposures in the valley of Sheepherd Creek, southeast of Huntsville. From that point the outcrop has been shifted several miles eastward by the great Huntsville fault. The continuation is therefore found in the divide, just east of Beaver Creek, north of the south fork of Ogden River. In that region, also, the distribution of the phosphate deposits is not readily determined, because the cover of Tertiary rocks conceals the outcrop, except in one of the principal canyons.

GENERAL CHARACTERISTICS AND RELATIONS.

Deposits of rock phosphate have been found at two horizons in the Paleozoic rocks of the district. The lower bed is of late Mississippian age and is probably too lean to be workable under present conditions. The upper bed is a part of the Park City formation (Pennsylvanian) and is generally of workable richness and thickness. H. S. Gale, while working in northern Utah and southern Idaho, found phosphate deposits also in the Jurassic rocks. In the Ogden district the Jurassic system is exposed only at Devils Slide, and there no detailed examination of the rocks was made.

The phosphate zone in the Mississippian limestone comprises black and brown shale, with black chert and limestone, alternating in thin beds through a thickness of 100 to 200 feet. Being easily eroded, the beds are rarely well exposed and the details of the succession are therefore not known. Some of the black shales thought to be phosphatic have been analyzed, but they show less than 20 per cent of calcium phosphate. Pieces of much richer oolitic phosphate rock, however, have been found on the outcrop of this zone, and on this account it is thought probable that there are some rich, though perhaps thin, beds of true phosphate rock in the Mississippian system.

The richer phosphate beds of the Park City formation are the only ones that have hitherto received attention. The phosphatic portion of the formation consists of an alternation of dark limestone, shale, and phosphate rock in beds ranging from a few inches to 15 feet in thickness. There appear to be all possible gradations between limestone and phosphate rock. The richest in phosphate is a hard black rock with distinct oolitic and generally nodular structure. When freshly broken the rock gives off a strong and disagreeable odor, resembling that of hydrogen sulphide. The outer surfaces of the oolitic beds turn gray on exposure, and in this condition they are more or less mottled with short white streaks and round dots. Microscopic examination shows that the rock consists of little round nodules closely packed together and cemented by some extraneous material, generally calcite. The oolitic bodies appear rich brown in thin section, but jet black in the mass. They show concentric structure only imperfectly. Some of the little white streaks above mentioned prove to be chips of shells made of aragonite or calcite. Among these shells marine brachiopods and gastropods are identifiable. The less pure varieties of the phosphate rock merely have fewer of the little oolitic bodies and a correspondingly larger proportion of the cement. In some beds the cement contains abundant sand grains, and rarely it is distinctly siliceous. The phosphatic shales carry 10 to 20 per cent of tricalcium phosphate, but seem to lack the oolitic structure. In them the phosphatic material is in a disseminated or macerated state. Some of the black limestones are richer in tricalcium phosphate than the shales, and a microscopic examination shows that they contain many scattered oolitic bodies.

In this upper phosphatic series two thick and eventually workable seams of phosphate rock have been found. These average 7 to 8 feet in thickness, but at one point, on Weber River, are 10 and 13 feet thick. In addition, there are several beds ranging from 1 to 3 feet in thickness which are separated by thin strata of phosphatic limestone and, taken together, may prove to be valuable. It is evident from the character of the beds and their association with marine fossils and limestone that they are of marine origin. This may be taken to mean that they are relatively uniform in value and thickness over considerable areas and that they do not change materially in depth. In other words, this material is purely an original concentration.

UTILIZATION.

The lean phosphate deposits in the Mississippian series are as yet wholly undeveloped. In only one place do they seem to have been even examined. The upper phosphatic series has, however, received more attention.

So far as known, little prospecting for phosphates was done in this region before the last decade, and as yet the phosphate deposits have been prospected in only a part of the district. Where most thoroughly explored, as in Weber Canyon, many shallow pits and trenches have been dug to find the position of the beds, and there are a few short drifts which penetrate into the formation. According to available information, however, there has been no shipment or sale of rock phosphate, or, if any, only such as may be regarded as experimental. No mining is now being carried on. The long haul to California, the nearest market at present, is expensive. The current price at the market is low. These two factors combine to render the mining of phosphate rock in Utah unprofitable to-day.

DESCRIPTION OF DEPOSITS BY LOCALITIES.

WEBER CANYON.

The phosphate deposits of this district are best exposed in the upper canyon of Weber River between Morgan and Devils Slide station on the Union Pacific Railroad. The lower phosphatic zone has not been recognized in this valley, but the upper zone is better known here than at any other point.

Weeks and Ferrier, in their reconnaissance report,[a] have described the general features of the deposits. The best-exposed section is that just west of Robison's ranch and is given below in detail. It comprises the lower part of the Woodside shale and all of the Park City formation. The line of division between the two is indefinite.

Section of beds near Robison's ranch, Weber Canyon.

	Feet.
Shale and sandstone; interbedded layers of gray, olive, and brown color	62
Shale, chocolate-colored, sandy texture	12
Shale, platy, greenish	4
Limestone, dense, hard, gray, in thin slabs, interbedded with olive shale (*Lingula*)	27
Shale, black to gray, with many thin beds of gray and pale-green limestone (*Lingula*)	80

[a] Weeks, F. B., and Ferrier, W. F. Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 315, 1907, pp. 454–455.

	Feet.
Limestone, grayish or olive, shaly, and shale	22
Limestone, hard, salient, with yellow pitted surface	2
Shale, gray to purplish, calcareous, with one thin bed of white limestone	11
Limestone, mottled gray and red, with brown chert seams and thin beds of shale	48
Shale, blocky, calcareous, gray	28
Limestone, gray, crystalline, mottled with red (many Pennsylvanian fossils near the top)	45
Concealed	40
Limestone, light gray, hard and somewhat argillaceous	70
Concealed by wash	45
Limestone, reddish and mottled	2
Limestone, light gray, earthy	37
Limestone, dark gray, brittle, and on the outside ashy	17
Sandstone, friable, calcareous, white	50
Concealed by slope wash	40
Limestone, black, with large nodules of black chert	9
Concealed by débris of shales, more or less phosphatic	143
Limestone, dense, black, and cherty	2
Shale, black and phosphatic	6
Limestone, dense, black, and cherty	5
Phosphate rock, black, partly oolitic (tricalcium phosphate average 46.1 per cent)	13
Limestone, phosphatic, black, cherty (tricalcium phosphate, 21.9 per cent)	5
Chert, hard and blocky, black	1
Limestone, black, with black chert nodules	4
Phosphate rock, rather uniform, dense black rock with many nodular and oolitic layers (tricalcium phosphate average 39.2 per cent)	10
Limestone, black and cherty	10
Limestone, gray, hard and blocky (tricalcium phosphate 8.8 per cent)	8
Limestone, black, with much chert, interbedded with layers of shaly phosphate rock 1 to 4 inches thick (tricalcium phosphate average 15 per cent)	40
Limestone, black and phosphatic (tricalcium phosphate 9.6 per cent)	3
Limestone, black, rather siliceous and hard (tricalcium phosphate 8.8 per cent)	1
Limestone, black, cherty (tricalcium phosphate 15.3 per cent)	2
Limestone, black, hard, and siliceous (tricalcium phosphate 11.8 per cent)	1
Limestone, dark gray, with great masses of black chert	157
Concealed by débris, chiefly of limestone	45
Limestone, sandy, gray, without chert	25
Breccia, sandy, light gray	20
Concealed by soil and débris	230
Sandstone, friable, white	40
Sandstone, white, with limonite concretions	10
(Breccia at base in other sections.)	
	1,232

It will be observed that in this section there are two thick beds of phosphate rock together with several thinner strata. It also appears that some of the limestone beds contain important quantities of tricalcium phosphate which may some day give them commercial value.

From Weber Canyon the phosphate beds have been traced both north and southwest across the mountains. (See fig 45.) On the south they bend to the southwest, but after crossing Tunnel Hollow and the next dry canyon beyond the formation passes beneath the thick Eocene deposits near the township boundary and does not reappear within this district. In that part of its course it is exposed

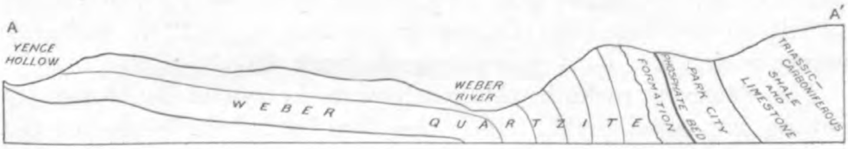


FIGURE 45.—Structure section through upper Weber Canyon, Utah, between Morgan and Devils Slide.

in many shallow test pits and trenches along the slopes of the ridges. There are also natural exposures of some value. Analyses of full sections of single phosphate beds here give 39 to 62 per cent of tricalcium phosphate.

North of Weber Canyon the outcrop makes a sharp bend, caused by a little overturned drag fold, and then continues north by west for a distance of 4 or 5 miles. Within this distance it is locally interrupted by thin caps of Eocene conglomerate and at the end it is completely buried by the same formation. Little prospecting has been done along this part of the outcrop, but there are fair exposures in ravines sufficient to show that the formation does not change materially in character within this distance.

SHEEPHERD VALLEY.

Sheepherd Valley is a small shallow valley tributary to Ogden River, 6 to 7 miles southeast of the village of Huntsville. It comprises the southeastern part of T. 6 N., R. 2 E., and the northeast corner of T. 5 N., R. 2 E. The hills there are low and heavily covered with gravel and soil and the valleys are neither deep nor rugged. For this reason exposures are poor. The phosphate beds themselves are not actually visible at any point. (See fig. 46.)

FIGURE 46.—Structure section of Paleozoic beds in Sheepherd Valley, southeast of Huntsville, Utah.

In this district both phosphatic zones have been found. The lower or Mississippian zone consists of gray and black phosphatic shales and limestone with characteristic fossils. It is much too lean to be of present importance. The details of the upper zone can not be ascertained without trenching, but it is probable that the succession is much like that in Weber Canyon, which is only 10 to 11 miles away. The beds reach the surface as they cross several low ridges. They are, however, thickly covered with soil, and at both ends they are completely buried beneath Eocene deposits. The residual soil lying upon the outcrops contains abundant pieces of the characteristic oolitic phosphate rock, like that in the better-known deposits in Weber Canyon. Analyses made by W. H. Waggaman, of the United States Department of Agriculture, of average collections of these pieces of float materials after sorting show the following percentages of tricalcium phosphate: Coarse gray oolitic rock, 72.9; fine gray oolitic rock, 70.3; hard gray vermicular rock, 69.6.

The Paleozoic rocks in this locality are known to be broken by several important faults. It is therefore hazardous to predict the position of the phosphate beds beneath the Eocene cover. There is no doubt that the whole succession is cut off at the great Huntsville fault, so that it does not extend farther northwest. Sheepherd Valley bears no evidence of having been explored for phosphate deposits. At the time of the writer's visit the very presence of such beds seemed to be unknown to the people of the vicinity.

BEAVER CREEK.

Beaver Creek is one of the principal branches of South Fork of Ogden River. The phosphate deposits in its vicinity lie chiefly east of the creek, and are exposed only in the second and third canyons east of it. On the divides they are buried by level Eocene strata 100 to 2,000 feet thick. (See fig. 47.)

FIGURE 47.—Structure section through Beaver Creek syncline, Utah.

The following is a partial section of the Carboniferous rocks in Dry Bread Hollow, one of the canyons tributary to South Fork of Ogden River:

Partial section of Carboniferous beds in Dry Bread Hollow.

	Feet.
Park City formation (top concealed):	
Limestone, buff and white, with poor Pennsylvanian fossils..	10
Concealed, shaly beds, probably in part phosphatic.........	130
Phosphatic beds, shale, limestone, and rock phosphate (detailed succession not observable).........................	118
Shale, gray, calcareous, with thin beds of limestone..........	180

	Feet.
Park City formation—Continued.	
Limestone, gray-white to dark gray, with shale partings	152
Concealed	54
Limestone, gray and crystalline	10
Concealed	85
Sandstone, soft, creamy white	125
Limestone, light gray, with chert nodules	20
Sandstone, white and calcareous, with one thin bed of limestone	75
Unconformity (?).	
Mississippian series:	
Limestone, gray, crystalline and fossiliferous	40
Shale, purple and gray, with layers and nodules of gray and bright-green limestone, mottled with red blotches richly fossiliferous	100
Limestone, gray, with large masses of chert	15
Limestone, dense, blue-gray	6
Limestone, thin bedded, pink, more or less sandy	10
Limestone, hard, blue-gray	4
Limestone, dark gray, and blackish dolomite, some nodules of gray chert	200
Limestone, thin bedded and shaly, gray to buff-white, with shale partings	80
Sandstone, light brown, calcareous	5
Limestone, dark gray to black, siliceous or dolomitic; fossils abundant, but poorly preserved	215
Limestone, gray to buff, thin bedded	60
Limestone, gray, crystalline and massive	12
Sandstone, buff and gray, calcareous	5
Limestone, siliceous, black	6
Limestone, earthy and dolomitic, brown to gray	62
Limestone, massive, brown	15
Phosphatic beds, black limestone with chert, brown shale, and shaly phosphate	100
Limestone, gray, cherty	20
Shale, phosphatic	6
Limestone; the body of the Mississippian limestone, the upper beds of which are dark and cherty.	

Both phosphatic zones are fairly well exposed in this locality. As usual, the lower is too lean to be of value at present; but the upper contains richer beds of phosphate rock essentially like those in Weber Canyon. The outcrop of the lower zone takes an irregular northeasterly course and its ultimate limit in that direction has not been found. The upper or workable zone is exposed for only a few miles along the west slope of Dry Bread Hollow. From a study of the structure of the region it is evident, however, that both zones occupy a shallow syncline underlying the divide between Dry Bread Hollow and Beaver Creek. The course of the outcrop of the workable beds could be determined by a moderate amount of drilling through the Eocene cover, but even without that it is possible to indicate the general position of the bed. Where not buried by Tertiary strata the upper zone is generally covered with soil, and there are no diggings affording better exposures. Débris upon the outcrop shows, however, that the zone contains beds of oolitic phosphate rock comparable to those at Robison's ranch in Weber Canyon.

One claim appears to have been staked on the Beaver Creek deposits, but very little work has been done on it and there seems to be little interest in the locality at present. This is due chiefly to the facts that the field is 20 to 30 miles from the nearest railroad and that the actual exposures are in a canyon which can not at present be reached by wagons. The cost of constructing roads and hauling the product to the railroads is so great in proportion to the current market price of the phosphate rock that these remote deposits can not be profitably mined for many years to come. They will, however, help to form a reserve which may be needed in the distant future.

OGDEN CANYON.

In the limestone cliff at "The Oaks" resort, about 2 miles below the upper end of Ogden Canyon, there is a zone of black shale and limestone, which proves on analysis to be decidedly phosphatic. The richest material is contained in two beds of black shaly rock, each about 2 feet thick. Analysis of a random sample from this bed, by W. H. Waggaman, of the United States Department of Agriculture, gives 42.5 per cent of tricalcium phosphate. In this exposure the usual oolitic texture was not seen.

At this point the beds are highly folded. The age of the zone is not known, but the rocks with which it is associated resemble the Mississippian limestone succession. The outcrop runs up the canyon slopes to the north and south, but can not continue much more than a mile in either direction because large faults there cut off the entire Paleozoic sequence. This deposit, although much richer than the others found in the Mississippian rocks of Utah, is so much disturbed that it can not be easily worked.

PROBABLE EXTENSION OF THE PHOSPHATE DEPOSITS.

The geologic structure of the district indicates that the Park City formation, which contains the workable phosphate deposits, continues northward and northwestward, beneath the Tertiary deposits, for many miles from the Beaver Creek locality. The Cache Valley syncline probably contains the formation buried under a considerable thickness of later deposits. From the known relations to older formations which are exposed it is believed that the outcrop of the phosphatic series runs northwestward along the west edge of Paradise Valley to the vicinity of Wellsville, and thence northward along the east base of the Wasatch Range for an undetermined distance. The outcrop lies under a cover whose depth is difficult to estimate, but which appears to conceal it completely. If, as the writer suspects, the east side of Cache Valley is bounded by a fault, then the phosphate deposits will not be found there, except at great depths. The southern part of the Morgan Basin may well, however, conceal good phosphate beds continued southwest from Weber Canyon.

SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relating to phosphates, gypsum (land plaster), and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum."

The government publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Those marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

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PENROSE, R. A. F. Nature and origin of deposits of phosphate of lime. Bulletin 46. 143 pp. 1888. Exhausted.

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SALINES.

THE SALT RESOURCES OF THE IDAHO-WYOMING BORDER, WITH NOTES ON THE GEOLOGY.

By CARPEL LEVENTHAL BREGER.

INTRODUCTORY AND HISTORICAL NOTES.

Valuable areas of salt-bearing land lie along the Wyoming-Idaho border in Bannock County, Idaho, and the middle-western part of Uinta County, Wyo. The deposits occur west of the Salt River valley, or Star Valley, as it is locally known. In the old days, before the advent of railroads in the West, relatively large amounts of salt were boiled from the brine springs in this region and were hauled by ox team to supply Idaho and Montana mining camps. The emigrants to the Northwest along the Lander route also drew upon this region for their salt. Indeed, some forty years ago, in the reports of the Hayden Survey, this area was briefly described as containing the finest salt works west of the Mississippi. In those days, from a couple of the brine springs on Stump Creek (Smoking Creek of the Hayden Survey), as much as 200,000 pounds of salt was boiled per month, selling in the late sixties at $1.25 a hundred pounds at the springs.

Since then, however, the area has decreased in importance. The railroads have passed it by; other salt works—those of the Great Salt Lake region—have taken its markets on account of easier railroad connection, and to-day all the Star Valley salt deposits together furnish annually only a couple of hundred tons or less, which is consumed by local ranchmen for table and stock use.

Interest in these salt deposits has recently been revived, owing to the discovery of rock salt beneath the brine springs in lower Crow Creek. James Splawn and H. Hokanson, in deepening these springs in 1902, encountered a formation of rock salt 6 feet below the surface and this has been penetrated for a thickness of 20 feet without reaching the bottom. The exceptional purity of the salt, its cheapness of production, and the probability of railroad connections in the near future lend interest to the deposits of the entire district. (See fig. 48.)

LOCATION.

The only rock salt encountered in the region to date occurs on the southeast side of the Crow Creek valley, along the route from Mont-

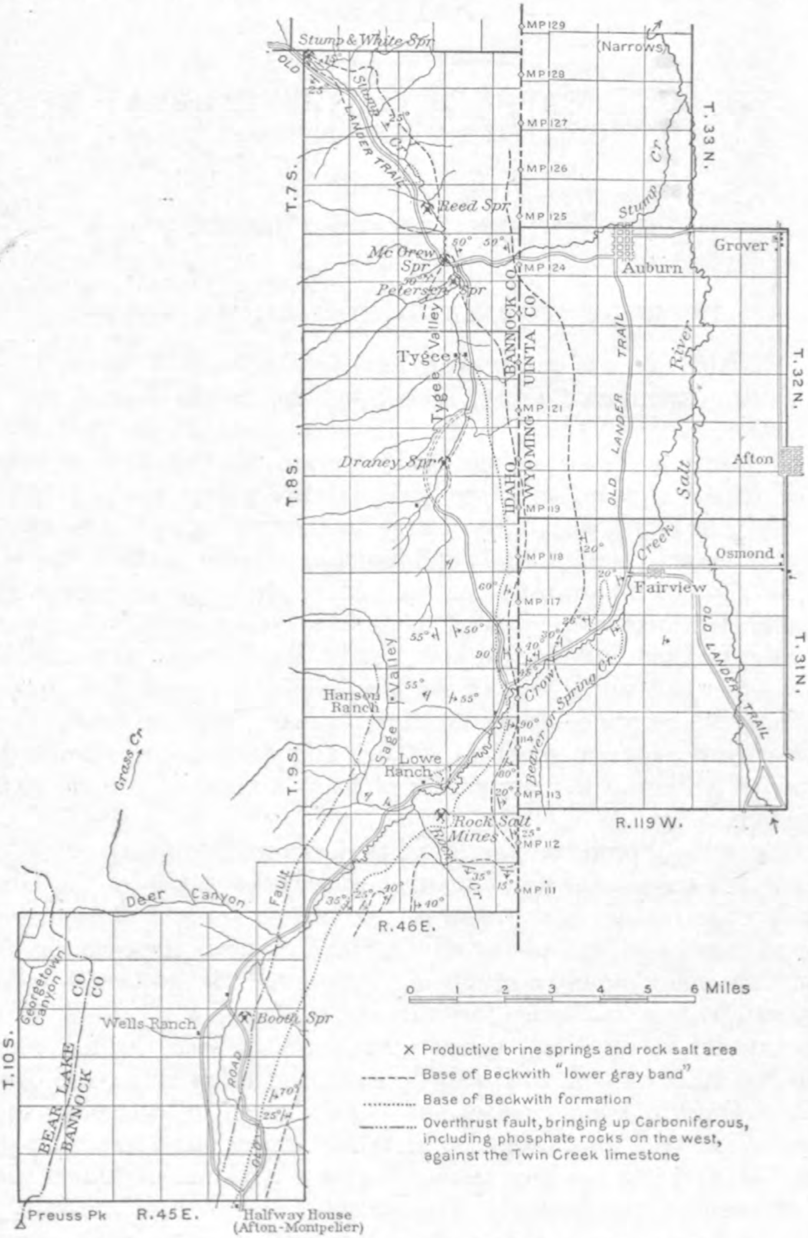

FIGURE 48.—Sketch geologic map of part of Idaho-Wyoming border country.

pelier, Idaho, to Star Valley. The locality is opposite the Lowe ranch, 38 miles northeast of Montpelier, and 12 miles southwest of

Afton, Wyo. The property is owned by John W. Booth, of Afton, who also owns a brine spring in upper Crow Creek, 6 miles nearer Montpelier. The latter has not been worked in recent years.

The principal operating brine springs are located on Stump Creek and in Tygee Valley, which are west of Star Valley, on the Idaho side of the state line. Most of the springs are near the junction of Stump and Tygee creeks. The Petersen spring, now owned and operated by Soren Petersen, of Auburn, is located on Tygee Creek, about half a mile southwest of the junction. The McGrew spring, owned and operated by John C. McGrew, of Stump Creek, is located on Stump Creek about half a mile northwest of the junction; and a mile farther north, up Stump Creek, are the Reed springs, owned and operated by Sydney Reed, of Auburn. Still farther up Stump Creek, about 5 miles above the Reed springs, occur the old Stump and White springs. These have not been operated in recent years. To the south, up Tygee Creek, the next worked spring is the Draney, 4 miles south of the Petersen spring.

Another salt-producing area is situated on the Wyoming side of the boundary line, south of Star Valley, on the route from Smoot and the upper end of Star Valley to Thomas Fork. This locality is on Salt Creek and is reported to be 7 or 8 miles northeast of Green's ranch, or the head of Thomas Fork. The plats of the General Land Office show it in the SW. $\frac{1}{4}$ sec. 26, T. 29 N., R. 119 W., east of the middle of the quarter. This brine spring was not visited.

THE SALT.

MODE OF OCCURRENCE.

The productive brine springs have no immediate relation to the solid rock formations occurring near by. The springs occur in the valley bottoms in barren patches of stony clay or gravel, which are rendered soggy by the contained brine. These salty places may be recognized at a distance by their gray color; in some of them a little salt incrusts the barren surface. Near by are terraces of reddish clays which will be described in connection with the geology.

A brine spring is made by digging a hole about 3 feet deep, 2 to 4 feet wide, and 3 or 4 feet long. This soon fills with water so saturated with salt that it frequently has a sirupy consistency or appearance when dipped up.

CHEMICAL COMPOSITION AND QUALITY.

Analyses of the rock salt of the district, made by Chase Palmer at the United States Geological Survey chemical laboratories, show:

Composition of rock salt of Idaho-Wyoming district.

Soluble ("salt")	91.79
Insoluble [a]	6.42
Moisture	.85
	99.06

According to Doctor Palmer's figures, the "salt" of the above analysis shows the following composition:

Analysis of "salt" from Idaho-Wyoming district.

Sodium chloride ($NaCl$)	98.900
Calcium sulphate ($CaSO_4$)	.817
Potassium chloride (KCl)	.261
Magnesium chloride ($MgCl_2$)	.022
	100.000

The rock salt is stained a reddish-brown color owing to the presence of clay containing ferric oxide. When the rock salt is dissolved in water and evaporated, the iron oxide disappears, leaving a brilliant pure-white product. This pure-white salt may be observed incrusting the ground near the water-filled shafts in the rock salt and along the ditches which are used to drain the shafts of water. Samples of this natural sun-dried white salt from the shafts and ditches, which probably represent more nearly average conditions for the entire body of rock salt, conform with the sample of raw rock salt analyzed in showing over 98 per cent of pure salt or sodium chloride, with practically negligible amounts of potassium and magnesium. The white salt has a slightly higher content of lime sulphate—1.48 per cent as compared with 0.817 per cent in the sample of raw rock salt analyzed.

A partial analysis of commercial table salt boiled from one of the Stump Creek brine springs was also made by Doctor Palmer. This analysis probably represents the usual quality of the salt boiled from the various brine springs of the Tygee-Stump Creek region. The analysis shows only a trace of magnesium and 0.73 per cent of lime (CaO), equivalent to 1.77 per cent of calcium sulphate ($CaSO_4$). The salt is thus similar chemically to the Crow Creek rock salt in the low

[a] Composed as follows:

Red clay	SiO_2	4.36
	Fe_2O_3	.27
	Al_2O_3	.88
	MnO	Trace.
Lime and magnesium sulphates and carbonates	MgO	.13
	CaO	.67
	SO_3	.11
	CO_2	Not determined.

or almost negligible magnesium content and the high percentage of pure salt or sodium chloride.

A comparison of the Idaho-Wyoming salts with other salts of the United States is indicated in the following table: [a]

Composition of various rock salts and brines.

SOLUBLE PORTIONS OF ROCK SALT.

	Sodium chloride (NaCl).	Calcium sulphate ($CaSO_4$).	Magnesium chloride ($MgCl_2$).	Calcium chloride ($CaCl_2$).
Crow Creek, Bannock County, Idaho	98.9	0.82	0.022	
Retsof, N. Y	98.7	.484	.055	
Pearl Creek, N. Y	96.9	.437	.103	
Petite Anse, La	99.1	.330		
Belle Isle, La	96.4	3.051	.74	
Saltville, Va	99.1	.448		
Do	93.05	2.400		

BRINES.

	Sodium chloride (NaCl).	Calcium sulphate ($CaSO_4$).	Magnesium chloride ($MgCl_2$).	Calcium chloride ($CaCl_2$).
Crow Creek, Bannock County, Idaho	98+	1.48	0.022	
Stump Creek, Bannock County, Idaho	98+	1.77	Trace.	
Pearl Creek, N. Y	97.48	1.68	.55	0.26
Syracuse, N. Y	95.33	2.30	.85	1.52
Bay City, Mich	91.95	2.39	2.48	3.19
Kanawha, W. Va	79.45		4.07	16.48
Pittsburg, Pa	81.27		4.80	13.93
Colorado City, Tex	95.86	1.63	1.46	.173
Salt Lake, Utah (refined brine, or commercial salt)	98.3	.68		.345

The above table shows that the Idaho salts are above the average in quality and compare favorably with some of the best salt produced. It may be stated that the chemical quality of salt is determined by (1) the amount of pure salt, or sodium chloride, in it and (2) the amount of impurities it contains. The impurities comprise (1) material which is usually neither harmful nor beneficial and consists chiefly of lime carbonate, gypsum, calcium chloride, clayey matter, etc., and (2) material which may be harmful, as magnesium chloride and calcium sulphate, which cause the finer grades of salt to "cake" or take up moisture, or soluble iron and iodine, which are usually considered physiologically injurious.

As to the physical quality of the salt, a brilliant pure-white product can be obtained from these deposits, as is shown by the incrustations about the shaft and ditches in the Crow Creek rock-salt deposit, and as may frequently be observed in the Stump-Tygee boiled or commercial salts, when these have been handled at all carefully. Commonly, however, the salt is boiled in smoke and cinder filled log cabins, where little or no precautions as to cleanliness are taken. The result has been that much of the salt lacks the brilliancy of whiteness requisite for the finer or table grades. However, as the

[a] After Harris, G. D., Rock salt, its origin, geological occurrences, and economic importance in the State of Louisiana, together with brief notes and references to all known salt deposits and industries of the world: Geol. Survey Louisiana, Bull. No. 7, 1908.

Idaho salt has been boiled largely for sheep and stock use, cleanliness has not been so imperative in its production. Brilliant pure-white salt has been and can be obtained from the brines when treated with merely ordinary care.

TREATMENT.

Present methods.—The equipment and methods of treatment in this region have been and are now very crude. The brine is dipped up in pails by hand and poured into sheet-iron shovel-shaped troughs or pans, which are about 10 feet long, 3 or 4 feet wide, and 10 inches deep. Each pan rests on a three-sided fire box, about 3 feet high, built of rough field stone held together with clay. The front of the box is left open for firing. The salt or brine is stirred with a shovel as the water boils off, and a common to medium fine grade product is the result. There is no equipment for milling or grinding. The pans and fire boxes, two or three in number, are inclosed in a log cabin. It is locally reported that boiling takes place more rapidly under cover than out of doors. As to fuel, there are no extensive forests in this locality, nor indeed any forests at all worthy of the name; but timber patches and windfallen logs in the mountains west of Tygee and Stump creeks furnish ample fuel for present needs. The hauling of fuel appears to be the most laborious and costly item. With railroad connections, cheap coal could be obtained from the Evanston, Kemmerer, and southwestern Wyoming fields or from possible coal fields in the Snake River canyon country, about 35 miles north of the salt district.

Possibilities of solar evaporation.—The abundance of sunshine and the dryness of the atmosphere in this region are very favorable conditions for the cheaper and cleaner process of solar evaporation in place of the more rapid boiling process which has heretofore been used. Should this process be attempted, however, the methods in use about Salt Lake and San Francisco, where brine is allowed to overflow extensive diked flats and evaporate, would be impracticable here, owing to the nature of the topography. The brine would have to be carried to evaporating pans, but in several places this could be done by gravity, the brine being piped directly from the spring, without pumping. The use of raised storage tanks, however, would be desirable. With a faucet supplying each pan and an automatic drip or flow of the brine from the faucet at nearly the rate of evaporation in the pan, the items of fuel and labor would be reduced to a minimum of expenditure, and the resulting salt would have a maximum of cleanliness.

Treatment of rock salt.—The rock salt on Crow Creek has been blasted out with dynamite in two surface pits or shafts about 20 feet square. One of these shafts is reported to have penetrated 20 feet of rock salt without reaching the bottom and to show at that depth cleaner salt than at the surface. Both shafts were filled with water at the time of the writer's visit. The water is drawn off prior to working by means of barrels and a crane, horses furnishing the power. The rock salt is sold in large, rough chunks or is hammered into finer fragments and sacked.

MARKET AND PRICES.

The salt of this district supplies the sheep herders and stockmen of eastern Idaho and middle western Wyoming. The raw, broken rock salt is now supplanting the boiled white salt for stock use on account of its cheapness. The finer grades of white salt are consumed for table use locally in Star Valley and vicinity, and a little finds its way now and then to Montpelier. In 1908 the rock salt of Crow Creek sold for 50 cents per 100 pounds sacked, or 40 cents in bulk. In 1909 the price of the rock salt was reduced to 40 cents sacked and 30 cents in bulk. The white or boiled salt of Tygee and Stump creeks sells for 75 cents per 100-pound sack for the finer or table and dairy grades and 50 cents for the coarser or stock grades.

ACCESSIBILITY.

Haulage to the nearest railroad station, Montpelier, Idaho, on the Oregon Short Line, costs at present 50 to 80 cents per 100 pounds, so that under existing conditions outside markets are out of the question. With a railroad in the Star Valley, however, the salt of this district would command the markets of western Montana, northern and western Wyoming, and northern and eastern Idaho. The Burlington, Union Pacific, Oregon Short Line, and independent railroad interests have surveyed routes that pass through Star Valley. Just now there are persistent rumors of construction by the Burlington in the very near future. There can be no question that in time the country will have railroad communication, for not only is the valley one of the richest and most progressive farming and grazing districts of the Wyoming-Idaho border country, but there is an abundance of minable phosphate rock, beautiful building stone, Portland cement, and lime in the mountains both east and west of Star Valley and Crow Creek, in addition to the salt deposits. All these resources might be profitably developed with railroad connections.

Star Valley furnishes the easiest route to upper Snake River, Pacific Creek, Two Ocean Pass, and the Yellowstone. Such a railroad would probably reach the valley via Crow Creek from the Oregon Short Line at Montpelier, Idaho, and would pass the Crow Creek salt deposits. A spur from Star Valley to the phosphate deposits in the mountains on the west would pass through Stump Canyon and tap the salt deposits in Stump and Tygee creeks. There has also been some talk of running a spur southward into Star Valley from a projected trunk line extending up Snake River from a point near Idaho Falls, instead of from Montpelier.

GEOLOGY.

General relations.—A geologic examination of the rock salt and brine springs indicates that rock salt of some kind will probably be found immediately underlying all the brine-spring areas. Contrary to expectation, however, the rock salt and salt springs have no intimate relation to the formations comprising the older bed rocks, except that the salt may have been originally derived from the Beckwith formation and that the occurrence of anticlines and domes near the present salt areas may have induced more or less local saline additions by underground waters. At present the workable salines are associated with a mass of reddish clays which form late Cenozoic valley deposits and which will be referred to at length in succeeding paragraphs.

Bed-rock formations.—The bed-rock formations occurring in the vicinity of the salt areas in Stump Creek include the Nugget sandstone [a] (nonmarine Lower or Middle Jurassic), Twin Creek limestone (light-colored marine shales and shaly limestones of Upper Jurassic age), and Beckwith formation (red sandstones and conglomerates of Jurassic-Cretaceous age). These same formations, particularly the Beckwith, appear also to constitute the bed rock in the Salt Creek area in Wyoming. At only one locality do rocks older than Jurassic occur in the vicinity of the salt deposits. This is at the upper salt springs on the east side of Crow Creek, 6 miles southwest of the rock-salt locality. Here Carboniferous cherty limestones form a rock ridge projecting up through the Pleistocene terrace of red clays.

Of the bed-rock formations, only the Beckwith (Jurassic-Cretaceous), as the probable original source of the salt, needs particular description here. This formation consists of red sandstones and conglomerates with two conspicuous gray bands. The lower gray band is a dark greenish-gray calcareous sandstone, 250 to 600 feet thick, and occurs 1,200 feet above the base of the formation. The lower 1,200 feet consist of red sandstones and shales, apparently without conglomerates. The conglomerates seem to be confined in the salt district to the interval above the lower gray band, constituting most of the rocks for a thickness of 850 feet. They are succeeded by the second or upper gray band, a massive limestone, more or less marly and light blue-gray in color. This rock attains a thickness of

[a] The Nugget, Twin Creek, and Beckwith formations were so named by A. C. Veatch (Report on the geography and geology of a portion of southeastern Wyoming, with special reference to coal and oil; Prof. Paper U. S. Geol. Survey No. 56, 1907). The Nugget, comprising the "Triassic Red Beds" of the Hayden Survey, has heretofore been considered of Triassic age, but the occurrence of Triassic faunas in the old "Permo-Carboniferous," underlying the Nugget, may relegate this formation to a higher horizon.

100 feet in Stump Canyon and northward, where it forms a resistant ledge that may easily be traced by its light color. The divisions of the Beckwith formation maintain these characters throughout the area covered by the present reconnaissance observations from Red Mountain, near the Afton-Montpelier "Halfway House," northward to the headwaters of Stump Creek, a distance of about 35 miles.

Post-Beckwith emergence.—There is some evidence that shortly after the close of the Beckwith deposition, in early Cretaceous time, the immediate vicinity of the salt region became permanently dry land, unaffected by the temporary resubmergence which brought in the later Cretaceous and early Eocene coal-bearing rocks near by in Wyoming.

Prior to the deposition of the Wasatch formation (Eocene) in the Western States the entire north-central Rocky Mountain country was permanently uplifted and subjected to profound folding and overthrust faulting by a major or Cretaceous-Eocene uplift. The intense erosion during and following this uplift resulted in the filling up of extensive early Tertiary fresh-water lakes in Wyoming, Colorado, and Utah—the Wasatch, Green River, Bridger, Wind River, and similar lakes. The salt region, however, does not appear to have been flooded by the waters of any of these lakes. The evidence suggests that it has been subject more or less continuously to erosion since the major Cretacous-Eocene uplift, and probably since the earlier Cretaceous, post-Beckwith uplift.

Oligocene (?) lake conglomerates and antiquity of Crow and Tygee valleys.—The region contains, however, remnants of perhaps minor lake beds which are of importance in showing the antiquity of Crow and Tygee valleys. These lake-bed remnants consist of light-colored conglomerates that are present on Crow Creek, in Tygee Valley, and perhaps also along Stump Creek. All these conglomerates occur near and in the valley bottoms and rise as a flanking crust along the hill slopes, mounting unevenly to various elevations, but, unlike the Wasatch, they are not spread over any of the higher hilltops. The pebbles, well rounded and worn, are a heterogeneous mixture, originating locally within the present drainage courses and limits. This last fact, coupled with the fact that there has been no important bed-rock erosion in the valley bottoms beneath the conglomerates, tends to prove that their age is more recent than that of the Wasatch. Bowlders of this conglomerate, already consolidated, occur as pebbles in the Pliocene or Pleistocene red stony clays. The age of the conglomerate is therefore apparently Oligocene or Miocene, probably the former. The great antiquity of the valleys of Crow and Tygee creeks, which must have been excavated before these Oligocene (?) conglomerates were washed into them, is thus established.

Post-Oligocene (?) probable aridity; salt formation.—On the withdrawal of the waters in which were deposited the Oligocene (?) conglomerates, the valleys of Crow, Tygee, and Stump creeks must have become again subject to erosion or possible filling. There are, however, in these valleys, no records of any more sediments in the interval between the Oligocene (?) conglomerates and the late Pliocene or Pleistocene red clays which overlie the salt. This suggests probable aridity in the salt region. During this period the salt deposits were formed. The neighboring regions afford better evidence of aridity.

Lake Bonneville beds in Bear Lake valley as climatic indicators.—During this interval there existed in the Salt Lake valley an extensive lake, of which the present Great Salt Lake is a drying-up remnant. This former lake, known to geologists as Lake Bonneville, overflowed in various early stages of its fluctuating level so far north as to flood Bear Lake valley, and drained northward into Portneuf River or into Blackfoot River. Its varying levels are commonly accepted as being due to varying degrees of climatic humidity. It is reasonable to suppose that notably arid intervals were included in such climatic variations, and that in the main the extensive retreats of Lake Bonneville represent arid intervals, and the advances indicate returning humidity. During some earlier, post-Oligocene stages of Lake Bonneville, probably Pliocene, there were formed the white marls and marly sandstones and conglomerates which are well developed southeast of Montpelier and about Georgetown, Idaho.

The deposition of these Pliocene (?) whitish marls was evidently succeeded by a period of climatic aridity, indicated by the lowering of the waters of Lake Bonneville and their temporary withdrawal from the Bear Lake valley, so that the marls were subjected to denudation.

Pliocene or Pleistocene return of humid conditions.—This arid period was followed, in late Pliocene or Pleistocene time, by a return of humid climatic conditions in which the waters of Lake Bonneville again rose, in fact higher than before, flooding the Bear Lake valley and overflowing to the head of Thomas Fork valley. This period of returning humidity marks the deposition in Lake Bonneville of the younger unconsolidated sands and silts which are finely developed in several slightly dissected terraces south, east, and northeast of Dingle. These deposits cover the earlier consolidated white marls.

Pliocene or Pleistocene red clays of Tygee and Crow creeks.—The period of returning Pliocene or Pleistocene humidity appears to have affected the salt region, where it seems to have developed glaciation in the Salt River Mountains, perhaps coincident with the late glaciation of the Wasatch, Uinta, Wind River, and Bighorn ranges. To this period also may be ascribed the red stony clays which cover all the salt deposits in Stump, Tygee, and Crow creeks. These clays are unassorted or unbedded and sandy and commonly contain an abundance of large angular bowlders. In places the clay may be nearly free of bowlders for a thickness of 50 feet or more over several acres. When such bowlderless portions are cut, as frequently happens, into rain-washed bare slopes, they acquire a characteristic "old rose" tint. This peculiar color is, however, observable only when viewed at a distance—a couple of hundred yards or more. By this characteristic color the clays and possible underlying salty areas may be recognized at a distance of half a mile or more. On close inspection the color of the clay is seen to be a nondescript brownish red or pinkish buff. The clay contains a small amount of disseminated salt, which may have been deposited originally with the clay or derived later by percolating ground waters from the underlying salt bodies.

The bowlders in the clay are mostly angular, and many of them are over a foot thick. Along Rock Creek, near the rock-salt deposits, the bowlders include 4-foot cubes of heavy ferruginous conglomerate of the Beckwith formation, which have been transported half a mile or more. The bowlders are scattered irregularly throughout the mass of clays and are nowhere in beds or otherwise assorted. In parts of the clay the bowlders are very abundant, especially in the lower part. Commonly a gravel of smoothly worn pebbles underlies the stony red clay.

The Pliocene or Pleistocene red stony clays occur in the valley bottoms along the foot of the mountains. They form delta-like terraces, the upper surface of which, though much dissected, appears to have sloped gradually away from the hills. These terraces rise for 200 feet above the present valley bottoms. They are not, however, continuous, but are isolated patches at or near the mouths of the larger incoming lateral streams. One of the best developed of these terraces is situated about the brine spring on upper Crow Creek. This terrace is half a mile wide and flanks the hills for a length of 2 miles. One of the best preserved terraces is that occurring about the rock-salt locality on Crow Creek, at the mouth of Rock Creek. Perhaps the largest terrace extends along the west side of Stump Creek and Tygee Valley, from a point near Tygee post-office northward to and beyond the Reed springs on Stump Creek. This terrace is 4 miles long and half a mile wide and embraces most of the productive saline areas noted in the present report.

In age the red stony clays over the salt are regarded as late Pliocene or more probably Pleistocene. Their unconsolidated character and the fact that they are still preserved in areas particularly subject to erosion suggest late geologic age; but their high elevation, their dissection, and the evident fact that they were formed under conditions not existing at present indicate a period preceding the Recent.

As to the origin of the red clays, it is apparent that their restriction to locations at or near the mouths of streams necessitates the inference that they are delta deposits of some sort. They are too flat-topped to be considered alluvial cones or morainal deposits, although they may originally have been such. They have been, at least part of the time, under water, which accounts for their terrace-like aspect. That ice was active in supplying some of the detritus is indicated by the massive, unbedded character of the clays and the irregular disposition, angularity, and large size of the bowlders. Indeed, it seems quite probable that the lake itself in which these delta-like terraces of red clay were planed off owed its origin to ice—to the presence of glaciers in lower Star Valley which dammed up the northward-flowing drainage of Salt River. That such glaciers existed is proved by the occurrence of extensive moraines in the lower Star Valley, as recorded by A. C. Peale, of the Hayden Survey.[a]

Relation of red clays to salt.—In the rock-salt locality on lower Crow Creek the stony clays rest immediately on the rock salt. For 2 feet above the salt bowlders are particularly abundant. In the brine-spring area on upper Crow Creek, as well as in all the worked brine areas along Tygee and Stump creeks (possibly except at the Draney spring), the stony clays are separated from the underlying salt bodies by round pebble gravels. From 2 to 6 feet of these gravels have been encountered in the springs or within a radius of a few yards. The gravels may represent disintegrated Oligocene (?) conglomerate or may indicate later creek gravels older than the red clays.

AGE AND ORIGIN OF THE SALT.

The salt was originally disseminated in small amount in the red sandstones, conglomerates, and shales of the Beckwith formation at the time these rocks were laid down in the shallowing and disappearing Jurassic-Cretaceous seas. The anticlines into which the porous Beckwith rocks are folded have localized the underground water circulation. On the crest of one of these anticlines are located all the productive salt areas on Stump Creek and lower Tygee Creek; the Draney spring is near the crest of the same anticline. The Crow Creek rock-salt area is on the crest of a prominent dome, at the mouth of a small tributary, Rock Creek.

The present productive salines were deposited during pre-Pleistocene time in the form of alkali flats at or near the mouths of incoming lateral streams or valleys. The salt-bearing waters reaching the main valleys sank into the gravels or spread over the surface. On evaporation or partial evaporation of the waters the salt was left behind, either on the surface or in the gravels.

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[a] Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1877, 1879, p. 641.

The hypothesis of pre-Pleistocene alkali flats and saline evaporation in the valleys to account for the present deposits is favored by the ideal conditions presented by the anticlinal folding of the salt-bearing, porous Beckwith rocks, coupled with the climatic aridity which has been shown to have preceded the Pleistocene. The long duration of the arid conditions, which may have extended nearly as far back as the period of the Oligocene (?) conglomerates, and the antiquity of the existing drainage features also support this hypothesis.

With the resumption of humid climatic conditions in the Pleistocene period the alkali flats were buried under an outwash of the stony red clays. These clays have blanketed the salt with a nearly waterproof cover which has protected the soluble mineral from being eroded or from being dissolved and carried away. Where recent erosion has washed the covering of Pleistocene red clays from the river bottoms the buried alkali flats yield their salt in the present productive brine-spring areas.

ESTIMATED EXTENT OF SALT DEPOSITS.

Probability of rock salt underlying the springs.—Solid salt deposits of some kind apparently underlie all the productive brine-spring areas. This is borne out by (1) the saturated character of the brines, (2) the similarity of geologic conditions in the single rock-salt area positively known to contain rock salt and in all the brine-spring areas, and (3) the fact that this rock-salt area itself was originally a brine-spring area similar to those of the present brine springs. Rock salt has been reported under the Petersen spring, in Tygee Valley, and under the Booth spring, on upper Crow Creek, but on authority of uncertain value. Whether the underlying solid salt will prove to be a mass of rock salt with small amounts of disseminated red clay, as at Crow Creek, or whether the salt occurs in gravels incrusting the pebbles is conjectural. Shallow digging or drilling would undoubtedly display the character and amount of salt available under the brine-spring areas.

Rough estimates of salt bodies underlying the brine springs.—Definite estimates of the amount of salt underlying the brine areas are, with the present data, impossible. Although the existence of rock salt underneath is more or less demonstrable, the thickness and continuity of the salt bodies, or old alkali flats, is problematic, particularly in the absence of any borings. From surface indications, however, it appears probable that the salt body to the west of the Stump and Tygee forks is more or less continuous from the Petersen spring northward to the McGrew residence, or nearly a mile. The Reed springs draw upon a probably large acreage of salt underlying the red-clay terrace near by, on the west side of Stump Creek. The acreage of the salt body supplying the Draney spring, in Tygee Valley, is wholly conjectural in the absence of borings. At the old Stump and White springs, on upper Stump Creek, the narrow valley and the presence of bed rock on both sides suggest a very small salt body, not much exceeding a couple of acres. The salt body supplying the Booth spring, in upper Crow Creek, if it underlies any large part of the red-clay terrace, would be very extensive. In the absence of diggings or other data, however, its extent is problematic.

Rough estimate of rock-salt body on Crow Creek.—The rock salt on Crow Creek has been penetrated for a thickness of 20 feet. Not only is the bottom not in sight, but the salt becomes purer at that depth, containing less clay than at the top. This suggests a great thickness at the particular points penetrated. The rock salt appears to underlie much of the terrace of red clays near the mouth of Rock Creek, but that the salt extends to any great extent under Crow Creek valley in front of the terrace seems improbable, though by no means impossible. The extreme north end of the terrace may not contain any salt; fresh-water springs emerge here. The south end of the terrace has been cut through by Rock Creek and may perhaps also prove now destitute of salt. Conservative estimates of the portion of the terrace regarded as in all probability now underlain by salt indicate an area of approximately 113 acres. On the assumption that an average thickness of 15 feet can be mined out or dissolved out, this area would yield a little over 74,000,000 cubic feet of rock salt. By weight this would produce a trifle over 5,000,000 short tons of soluble salt (the rock salt being assumed to average 8 per cent clay and solid matter and 92 per cent soluble salt).

Possibility of salt in Star Valley.—The existence of anticlines in the sandstones of the Beckwith formation in the hills on the west side of Star Valley and the presence in places of the Pleistocene stony red clays suggest the possibility that old buried salt flats may exist under portions of the valley. None of these have yet come to light, so far as known, but unless local conditions prevented the formation here of pre-Pleistocene salt flats it is probable that future diggings may discover buried salt bodies in some portions of Star Valley proper.

SUMMARY AND CONCLUSIONS.

The workable areas along the Idaho-Wyoming border consist of isolated patches or salt bodies. These were formed during a long period of pre-Pleistocene climatic aridity by salt-bearing waters from the lateral streams (either surficial or underground drainage), which reached the valley bottoms, evaporated, and left their salt behind, either on the surface or in the gravels. The existence of anticlines and domes near by in the porous sandstones and conglomerates of the Beckwith formation had aided in the accumulation of salines to intensify the salinity of some of the drainage. The salt flats produced have been preserved by a covering of Pleistocene stony red clays.

Although the salt bodies or old alkali flats are thus meager in extent, especially in comparison with the other prominent salt-producing areas of the United States, the conservative estimate of 5,000,000 tons for the Crow Creek rock-salt body and the possibility of a larger salt body near the Tygee and Stump Creek forks indicate that the amount of salt apparently in sight in some of the present areas would be sufficient (if proper railroad connections existed) to yield returns on large-scale workings for a long time. It also appears quite probable that all the areas, including the smaller brine springs, contain sufficient salt to return the sums that may be advisedly invested in their development.

As to quality, salt can be easily obtained here which is above the average in chemical purity, as is indicated by the representative analyses given. This salt could be produced most cheaply and with the maximum of cleanliness by a process of solar evaporation.

At present the market for the salt of the area described is limited to the immediate vicinity, owing to the absence of railroad connections. With a railroad in Star Valley, however, the salt of this area would command the markets of eastern Idaho, western Wyoming, and much of Montana.

DEPOSITS OF SODIUM SALTS IN WYOMING.

By Alfred R. Schultz.

INTRODUCTION.

Wyoming is noted for its salt, sulphur, iron, alkaline earth, mud, and hot springs, which are scattered all over the State. In addition to the deposits formed from these mineral springs there occur in Wyoming extensive deposits of soluble salts of sodium and magnesium—sodium sulphate, sodium carbonate, and magnesium sulphate—for the most part in small drainage areas or basins which have no outlet. Many of these depressions are locally called "lakes," as they form the lowest parts of the basins and during the spring and early summer months are covered with shallow waters. During wet seasons some of these "lakes" contain water throughout the year. A few of the soda lakes, as the Wilkesbarre and Wilmington lakes, never become dry and form no solid deposits, the soda being entirely in solution. The soda basins or "alkali lakes" are more or less irregular and the deposit of salt in the different parts of the basin of varying thickness. The salt beds are usually very thin along the edge of the basin and thicken toward the center. In some localities these alkali deposits have been utilized, but for the most part no effort has been made to develop them for commercial purposes. A few of the mineral springs in Wyoming have been developed for their medicinal value and have attained considerable commercial success.

In the Yellowstone Valley salt springs are numerous, but thus far no effort has been made to utilize the brine in the manufacture of salt. Extensive beds of salt of great purity occur in Crook County west of the Black Hills and in western Uinta County along the Salt River Mountains. Salt springs and deposits are known to be present in Bannock County, Idaho, and western Uinta County, Wyo., along the state line. In both of these localities salt has been produced for many years. The salt-producing area in Uinta County, Wyo., lies south of Star Valley, on the route from Smoot, in upper Star Valley, to Thomas Fork. The salt developments are located on Salt Creek, in the SW. ¼ sec. 26, T. 29 N., R. 119 W., about 8 miles northeast of Green's ranch or the head of Thomas Fork. The brine springs in this part of Wyoming are similar to the workable springs along the Idaho-

Wyoming border described by C. L. Breger in the preceding paper in this bulletin. It is highly probable that in this vicinity rock salt will be found beneath the surface similar to the rock-salt deposits discovered in 1902 on lower Crow Creek, a tributary to Salt River in eastern Idaho.

No attempt will be made in this paper to describe all the various salt deposits, mineral springs, and alkali flats in Wyoming or to give their distribution. A few of the largest and most important soda deposits and lakes will be briefly described, and a short discussion of the sodium-carbonate developments at Green River will be presented.

ALKALI DEPOSITS.

LAKES AND PONDS.

In various places in Wyoming there are thick deposits of high-grade soda in the beds of dry lakes or ponds, ranging from those a few feet in diameter to some that cover several hundred acres and lying at various elevations above the sea. Most of these alkali deposits seem to have a common origin, and they occur in all parts of the State. Alkali deposits are found here and there and alkali crusts form in abundance about all depressions, ponds, or "dry lakes" in geologic formations above those of Paleozoic age. They are most abundant in the Triassic beds, but occur in all the geologic formations from the Paleozoic down to the soils of the present time. The Mesozoic and Cenozoic formations contain many times as much alkali as the Paleozoic and lower rocks.

In some localities the amount of alkali stored in clays and shales is enormous. In the midst of the Red Desert there are clay beds of a dull-red color which have a rather pulverulent surface during dry weather. Only a few inches below the surface in many of these beds the alkali amounts to 30 or 40 per cent of the mass. When there is a slight rainfall the clay forms a protective covering and none of the alkali escapes. During periods of heavy rain, which rarely occur, the water often finds its way through this clay mantle and, following the alkali surface, carries away all the salts that will pass into solution. At such times the water draining from these places and entering the soil is nearly saturated with salts. In many of these small basins the alkali is left unprotected on the surface, where it is deposited on the evaporation of the water that brings it into the depression either by drawing it up from below through capillary attraction or by carrying it in from the surrounding country on the surface or through underground seepage.

In the fall, when the surface becomes a powdery mass, the winds carry away the soda in huge clouds of dust. The air is so filled with the desiccated salts that anyone at a distance of 4 or 5 miles from these beds and unacquainted with the conditions would pronounce the dense white clouds the result of some great conflagration. Often in the fall, when the wind is blowing from 40 to 60 miles an hour, anyone standing on the slope of the mountains can see a cloud of alkali dust rising to a height of 50 to 100 feet from every dry alkali pond and extending for some distance beyond its borders. In this way the annual supply of alkali washed into these depressions is to a certain extent reduced, but this reduction is not equal to the storage and in consequence the deposits are increasing in volume. There are numerous alkali flats in the region of the Red Desert similar to the flats east of the Boärs Tusk, in T. 23 N., R. 104 W., and north and east of Black Rock, in T. 22 N., R. 101 W. Some of these are large, others small, but the history is much the same for all. Most of these flats are too small to be taken into consideration in this preliminary paper.

ORIGIN.

The large size of some of these salt deposits and their number and areal distribution have given rise to considerable speculation as to the source of the soda and magnesium compounds in the "soda lakes." It is believed by some that the salt is brought in by the water draining into the lakes from the surrounding country and is held in solution until the water evaporates, the crystallized material being deposited in beds ranging in thickness from a few inches near the borders of the lake to several feet near the center. Others believe that the soda is brought from other sources through the agency of springs. Both of these theories are tenable and to account for all the conditions and the observed facts regarding the deposits in the various lakes both theories are required.

It was formerly believed that much if not all of the alkali in the arid West was formed through the decomposition of granitic rock by the oxidation of the feldspars, but it is now known that none or at best very little of the alkali so abundant in Wyoming has originated through the direct decomposition of the granites in the vicinity of the granitic masses.

During the late eighties it was argued that the alkali found in extensive deposits or dry lakes in Wyoming was derived largely from springs in the immediate vicinity of some of these lakes. This theory is set forth by Ricketts [a] in the following manner:

> It was at first generally supposed that the soda arose simply by the evaporation of surface waters that had drained through the soil into the lakes and in this way dissolved the sodium salts. For many reasons this supposition was doubted, and it is now proved to be incorrect. While it is true that the soda deposits occur in basins with no visible outlet, there are also a great number of such basins with lakes or ponds in them which contain only alkali waters, or, when dry, but a thin crust of the alkalis or alkaline earths. The true soda deposits, on the other hand, though the basins in which they occur are not of abnormal area, always contain exceedingly large quantities of the salts peculiar

[a] Ricketts, L. D., Ann. Rept. Territorial Geologist Wyoming, 1887, p. 46.

to them, and these are pure and are not, as a rule, a mixture of sodium, magnesium, and calcium salts, which would be present if they were the result of the evaporation of surface waters. Mr. Arthur L. Stone, of Laramie City, has found that the Union Pacific Lakes near Laramie are fed by springs whose waters are highly charged with sodium sulphate. Finally, at Rock Creek there are in one and the same basin some lakes containing pure sulphate of magnesium, others which contain with the latter also large quantities of sulphate of sodium, and still others which contain no deposits whatever. For these reasons it seems very certain that all of the large deposits of soda in Wyoming arise from the evaporation of the waters of springs which feed the lakes and which are highly charged with soda.

In a later report[a] Ricketts makes the following statement:

There can be no question but that these deposits all arise through evaporation of the water of mineral springs which feed into lakes and have no way of escaping.

That Ricketts as well as others was led astray in making his deductions on the origin of the Wyoming soda deposits was in part due to the assumption that the salts were pure and not, as a rule, a mixture of sodium, magnesium, and calcium salts. That the salts in these "lake deposits" are seldom pure is clearly set forth by Knight:[b]

The salts stored in the basins, either in solution or as a solid, compare in chemical constitution with the salts found in the soils and as efflorescent crusts. To be sure, the sulphate of lime is quite insoluble and in consequence is very rapidly precipitated when concentrated in depressions. The difference in the salts found in the same basin but in different depressions is very interesting but is accounted for in several ways. In the first place, there is no deposit of pure Epsom salt or magnesium sulphate, for it always contains some Glauber salt or sodium sulphate, unless one selects pure crystals for analysis. The relations between these deposits with varying composition should be considered in discussing their origin. The deposit rich in Epsom salt occupies the lowest point in the basin. Magnesium sulphate is more soluble than sodium sulphate at ordinary temperature, and in the case of a heavy rain when the soda has been deposited in the small depressions above the large ones, the freshet would carry away the magnesium sulphate to the lowest depressions, where it is found. The magnesium sulphate, being much more soluble, would also tend to store the Epsom salts in the lowest depression on account of the percolation of the water, rich in these salts, to the lower level.

Knight is the chief advocate in recent years of the theory that the Wyoming soda lakes are formed by the soda brought in by the water from the country draining into the lakes. More than any other one man he has carefully studied the Wyoming alkali deposits and proved that they were formed by accumulating salts that remained after the evaporation of the water in the small basins and "dry lakes." This theory can best be set forth by quoting at length from Knight's report as follows:[c]

While it is possible that considerable alkali is being brought to the surface with spring water, the amount is insignificant as compared with the supply that is constantly being derived from the soils and other formations.

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[a] Ricketts, L. D., Ann Rept Territorial Geologist Wyoming, 1888-1889, p. 67.

[b] Knight, W C, and Slosson, E. E, Alkali lakes and deposits: Bull. Wyoming Exper. Sta. No. 49, 1901, pp. 84-85.

[c] Idem, pp 85-88.

In looking into the "spring" theory careful observations were made at nearly all of deposits of note in the State. In no instance were springs found on a level with or above the deposit or water line. In five instances deposits were found without any appearance of moisture, and in digging into the mass no water was found. In other places the deposits were underlaid with a saturated solution of sodium sulphate and other salts, while in other localities the soda is always in solution. In the latter instance I believe that there are springs that feed the lakes; but whether or not the waters are rich in sodium or other salts has not been determined. There are many instances where the water came up and filled an opening made when blocks of the salt were being removed, and following this the opening was immediately filled with crystallized salts. This was in all probability due to the water below the deposit and the superincumbent weight was sufficient to force it to the surface. In one instance of this kind when the cube of soda was taken out for the world's fair the bed of salt was pierced several times with an inch bar, and through this opening the water came in at the rate of 450 gallons per hour. This solution had a gravity of 31° Baumé, and an analysis made for sulphur trioxide proved it to contain 19 per cent SO_3, corresponding to 76 per cent of Glauber salts or 57 per cent of Epsom salts. Both these salts were present. While the springs play some part in the accumulation of the soda deposits, they must be considered of minor importance as compared with other factors.

From personal observations it is my opinion that the alkalies have been derived from the soils and the strata which surround the deposit or drain into them. In localities where there are vast beds of shale and clay with undrained depressions we always find alkali being stored. There is no exception to this statement so far as I am aware. In hundreds of places there are slight depressions at the present time, where there is an accumulation of salts going on; but no one has pretended to measure the amount that accumulates annually.

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In summing up the evidence relating to the origin of the so-called alkali salts of Wyoming I have arrived at the following conclusion: Primarily the alkali has been produced by the decomposition of the various rocks containing these elements. These salts appear to have been formed extensively during the Mesozoic and Cenozoic eras, but in place of being stored in deposits were carried down with the sediments. Later through the mountain-making agencies these formations were brought to the surface and through the influences of decomposition and erosion have been converted into soil. The salts have remained in the soils so formed, since there has not been sufficient water to leach them out. The decomposition of the rocks is still in progress, and from this source and the storage already accumulated in the soils the deposits of alkali have been formed and are being increased.

There are hundreds of places in Wyoming where sodium salts are being accumulated; but as a rule they do not form beds of much consequence. Upon the Laramie plains alone there are no less than one hundred slight depressions containing more or less alkali. In the majority of cases the alkali is found in the fall of the year in a thin crust upon the bottom of small ponds which have recently dried up. The deposits which are to be discussed under the above heading are those where there has been a considerable storage of alkali and where it forms masses of sodium sulphate and associated salts to a thickness of 1 or more feet.

Since the alkali deposits look very much alike and have been deposited under similar conditions a general discussion of the beds will not be out of place at this point. In many instances the name alkali lake has been applied to the soda deposits, since in the early spring and often into late summer the deposits are covered with water. The water accumulates through the melting snows and rain and is often a foot or two in depth; but beneath this one can find a solid bed of crystallized alkali. Later in the season these so-called lakes are deposits of snow-white alkali, which when seen from a distance resembles a snow-covered basin.

The deposits vary in size from a few to 100 acres, and in thickness from a few inches to 10 or possibly 15 feet. The salts are always found resting upon a muddy bed, which is usually very soft, and without difficulty one can force a pole to 5 or 6 feet below the hardened deposit. The mud varies in color from almost black to bluish, and contains many crystals of sodium sulphate. When it is removed from the bed it has a strong odor of sulphureted hydrogen, and often one is conscious of an odor resembling that rising from dissolving sodium hyposulphite. This mud always contains quite a percentage of salts found in the deposits.

For many years it was supposed that all of the alkali deposits were of crystalline purity, and for commercial purposes they could be quarried, dried, and made ready for the market. Upon making a careful section of several deposits it was found that

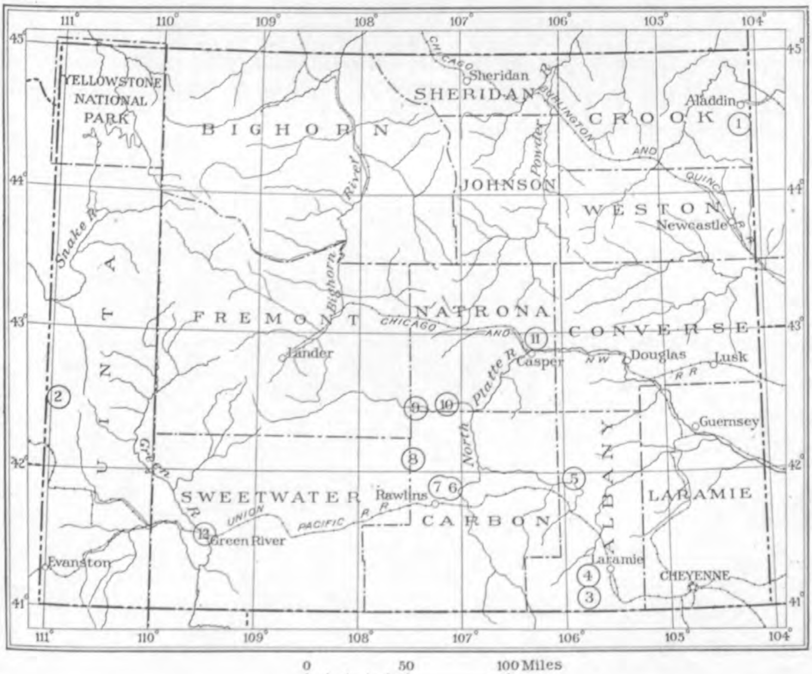

FIGURE 49.—Map showing location of the more important soda deposits in Wyoming. 1, Crook County salt deposits; 2, Uinta County salt deposits; 3, Downey soda deposits; 4, Union Pacific soda deposits; 5, Rock Creek soda deposits; 6, Rankin soda deposits; 7, Dillon soda deposits; 8, Bothwell soda deposits or Bull Spring soda lake; 9, Morgan soda deposits; 10, Independence group soda deposits; 11, Gill soda deposits; 12, Green River soda deposits.

none of the beds were pure; but were alternating layers of salts, sand, and mud. The thickness of the sodium sulphate bands depends upon the rapidity with which the salts were washed into the depression. It appears that at the close of each season, or during the fall, all of the water was evaporated and upon the alkali deposit the winter's wind carried the usual amount of sand. On the following spring the melting snow and rains carried into the depression not only the salts, but also muddy water which settled to the bottom and made a stratum of mud or muddy deposit. In some instances the accumulations of alkali of one or more previous seasons might have been dissolved, and all of the sand and mud concentrated at the bottom of the deposit or stratum. It is a rule that the deposits are mixtures of the various salts arranged in bands of varying thicknesses and alternating with other bands containing large percentages of sand or mud.

DISTRIBUTION.

Soda lakes of considerable size and importance are located in Albany, Carbon, Natrona, Sweetwater, Fremont, and Johnson counties. (See fig. 49.) Many of the lakes are small and of little or no economic importance. Others are large in areal extent but contain very thin beds and so far as investigation has progressed seem to be of no commercial value.

Of the counties above mentioned Albany, Carbon, and Natrona contain the most numerous soda lakes. The lakes outside of these counties, as well as many of those within these counties, have no commercial value at the present time. Some of the more important lakes are briefly described in the accompanying table, which gives the geologic horizon, location, and approximate area of the basin, the thickness of the salt beds where known, and such additional information as bears directly on the deposits themselves.

Statements regarding some of the larger alkali deposits in Wyoming.

Location.	Name of alkali deposit or lake.	Number of deposits or lakes.	Area covered.	Thickness or depth.	Age of underlying rocks.	Remarks.
Albany County.			*Acres.*	*Feet.*		
22 miles southwest of Laramie; secs. 15, 21, 22, T. 13 N., R. 75 W.	Downey	3	100	0–10	Triassic	North Lake, the lowest of the three, has a good quality of soda. Middle Lake, the second lowest, has a good quality of soda. South Lake is soft and miry and contains no hard beds of soda.
13 miles southwest of Laramie.	Union Pacific	4	60	0–40	Cretaceous (Benton)	Big Lake, Track Lake, Red Lake. Besides four large lakes that vary from 4 to 40 acres, there are near by scores of depressions containing small quantities of alkaline water or salts.
12 miles northwest of old Rock Creek station, Union Pacific Railroad.	Rock Creek group	Numerous.	Several hundred.	....	Triassic	Numerous small depressions contain alkali; the largest covers about 90 acres. The lower parts of these depressions contain more magnesium sulphate; the higher parts contain sodium sulphate. There are about 26 small lakes or ponds, many of which are of no importance on account of small size or thin deposits.
	Brooklyn	1	90	0– 1		
	Philadelphia	1	40	4– 7		
	Chicago	Group.	1–10	0– 6		
Carbon County.						
3 miles northeast of Browns Canyon.	Rankin	Numerous.	Several.	....	Cretaceous	These deposits are usually under water.
7 miles northeast of Rawlins	Dillon	....	....	....	....do	
30 miles northwest of Rawlins, secs. 23 and 26, T. 25 N., R. 89 W.	Bothwell deposits or Bull Spring Lake.	1	30	0–20	Tertiary	Part of Red Desert. There are several smaller alkali deposits to the west and south that drain into this one. Red Desert has numerous small alkali lakes.
Natrona County.						
7 miles below Split Rock postoffice, south of Sweetwater River; T. 28 N., R. 88 W.	Morgan	1	100	0–15+	....do	This lake lies in a long, narrow depression south of Sweetwater River in the southwest corner of Natrona County. The thickest part of the alkali deposit occupies about 6 acres.
Sweetwater Valley, near Independence Rock.	Independence group	Many.	....	....	....do	The alkali deposits occur in two pronounced old river channels north of the present Sweetwater River. The channels are about 3 miles apart and are separated by a marked divide. The lakes in Series I, or the Dupont Lakes, occupy the southern channel, and those in Series II, or the Berthaton Lakes, the northern channel. The Dupont claims comprise also many lesser lakes of little importance.
	Series I (Dupont claims):					
Sec. 12, T. 29 N., R. 87 W.	New York and Philadelphia	....	110	0–20		Two claims on one lake.
Secs. 23, 10, and 11, T. 29 N., R. 86 W.	Wilmington	....	160	0–40+		Lake containing water throughout the year.
	Wilkesbarre	....	50	....		Do.
	Omaha	....	4	0– 8		Large percentage of sodium carbonate and bicarbonate. Used by the Mormons for raising bread.
	Series II (Berthaton claims).	2	640 80	....		All lie in an old channel of Sweetwater River about 3 to 4 miles in length.
8 miles northeast of Casper; sec. 26, T. 35 N., R. 78 W.	Gill	4		20+	Cretaceous	Soda pits have been sunk to a depth of 12 to 20 feet, but the entire thickness of the soda has not been determined.

CHEMICAL COMPOSITION.

The alkali deposits in the "soda lakes" may be divided into two classes—(1) those that contain considerable quantities of carbonates and consist chiefly of sodium carbonate, sodium sulphate, and sodium chloride, and (2) those that contain very little carbonate and consist chiefly of sodium sulphate, sodium chloride, and magnesium sulphate. Traces of other salts, as potassium, lithium, iron, aluminum, manganese, borates, nitrates, sulphites, and phosphates, are associated with these principal salts in many of the deposits. Regarding the salts of the "soda lakes," E. E. Slosson makes the following statement:[a]

> The salts found in the soda lakes are the same as those which occur in the soil of the surrounding region and form alkali crusts as they are drawn up from below with the water and left on the surface as this evaporates. Of these salts the most abundant in Wyoming is sodium sulphate. This exists in two forms—with water of crystallization and without. The former has the chemical symbol $Na_2SO_4.10H_2O$, and is called mirabilite in mineralogy and Glauber's salt in medicine. The pure crystals contain 55.91 per cent of water and 44.09 per cent of the dry sulphate. It forms large, transparent crystals, which, when exposed to the air, lose all their water of crystallization and fall into a fine white powder (Na_2SO_4), known as thenardite.
>
> Magnesium sulphate ($MgSO_4.7H_2O$), epsomite, or Epsom salts, is found as long, needle-shaped crystals or short, thick crystals about a quarter of an inch thick, and contains 51.2 per cent water of crystallization, which it loses in part when exposed to dry air.
>
> Sodium carbonate ($Na_2CO_3.10H_2O$), sal soda, or natron, contains 62.9 per cent water of crystallization when fully hydrated, but will lose from a half to nine-tenths of it to dry air.
>
> Sodium chloride (NaCl), common salt, or halite, contains no water of crystallization.

The chemical composition of some of the Wyoming alkali deposits is shown in the following table, compiled from the report of Knight and Slosson, already cited:

[a] Knight, W. C., and Slosson, E. E., Alkali lakes and deposits: Bull. Wyoming Exper. Sta. No. 49, 1901, p. 106.

Chemical composition of some of the larger Wyoming alkali deposits.

Name of alkali deposit or lake.	Sample as received.											Calculated as dry salts.							
	Laboratory No.[a]	Water.	Insoluble.	Sodium sulphate.	Sodium chloride.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Magnesium chloride.	Sodium borate.	Sodium bicarbonate.	Sodium sulphate.	Sodium chloride.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Sodium bicarbonate.	Analyst.[b]	Remarks.
Albany County.																			
Downey	162	44.41	0.11	28.24	0.28			26.96				50.90	0.50			48.60		S.	Crystallized salt in middle of northern Downey Lake.
Do	178	55.43	2.24	39.17	.12		0.80	2.24				92.54	.28		1.89	5.29		S.	Clear crystal mixed with mud and water 6 feet below surface.
Do	163	74.60		6.93	1.16			17.31				25.61	5.28			70.11		S.	Solution above sample No. 162.
Do	176	72.79	.13	12.77	.86	0.05		13.40				47.18	3.17	0.18		49.47		S.	Solution in blast hole from which No. 178 was taken.
Do	173	75.89	.02	11.50	.45	.06		12.08				47.74	1.86	.24		50.16		S.	Solution from southern Downey Lake.
Do	175	49.29	.51	19.67	.50			30.03				39.18	1.00			59.82		S.	Crystallized salt from ditch in southern Downey Lake.
Do	182	55.94	.10	41.02	.12			1.82				95.46	.28			4.26		S.	Pure crystal at north end of northern Downey Lake.
Union Pacific (Big Lake, Track Lake, Red Lake).	172	55.55	.09	42.75	.70			.91				96.37	1.58			2.05		S.	Marketable dried soda.
Do	A	46.87	13.86	34.85	1.16		1.45	.97				94.23	3.14			2.63		P.	Average sample from lakes.
Do				44.90			1.75	.60	6.43	1.46								P.	Specific gravity 1.0487.
Do				75.63			1.46	.70	3.00	1.21								P.	Specific gravity 1.0725.
Do				93.07			2.01	1.43	4.16	.75								P.	Specific gravity 1.0887.
Rock Creek group (Brooklyn, Philadelphia, Chicago, and others).	88	44.50	.65	12.13	.38			42.34				22.13	.69			77.18		S.	From surface of largest lake.
Do	89	48.03	.08	24.49	.24			27.16				47.19	.46			52.35		S.	From depression in a small lake.
Do	90	51.08	1.13	10.22	.46			37.11				21.41	.95			77.64		S.	From large deposit about 1 mile north of No. 88.
Do	91	49.66	.58	40.52	.42			8.82				81.43	.84			17.73		S.	From deposit immediately north of No. 90.
Do	92	27.71	64.96	1.20	.66			5.47				16.33	9.06			74.61		S.	From mud beneath No. 89.
Carbon County.																			
Bull Spring or Bothwell	158	46.99	4.15	44.92	1.32			2.62				91.94	2.69			5.37		S.	Sampled at surface.
Do	159	42.99	1.79	55.05	.17			Tr.				99.68	.32					S.	Sampled at 1 foot depth.
Do	160	17.08	10.71	69.16	.84			2.21				95.78	1.16			3.06		S.	Sampled at 2 feet depth.
Do	157	34.11																S.	Selected crystals.
Dillon	168	35.18	8.57	38.22	3.75		13.27	1.01				88.92	2.35			8.73		S.	Surface deposit.

[a] Numbers used by E. E. Slosson in Bull. Wyoming Exper. Sta. No. 49.

[b] S., E. E. Slosson; P., H. Pemberton and G. P. Tucker; A., D. H. Attfield; R., L. D. Ricketts.

Chemical composition of some of the larger Wyoming alkali deposits—Continued.

Name of alkali deposit or lake.	Sample as received.											Calculated as dry salts.							
	Laboratory No.[a]	Water.	Insoluble.	Sodium sulphate.	Sodium chloride.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Magnesium chloride.	Sodium borate.	Sodium bicarbonate.	Sodium sulphate.	Sodium chloride.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Sodium bicarbonate.	Analyst.[b]	Remarks.
Natrona County.																			
Morgan:																			
Top crust		6.93	0.43	84.86	1.55	6.23						91.60	1.68	6.72				A.	Sampled by D. H. Attfield in Febru-
New deposit		53.89	.41	43.93	.77	1.00						96.14	1.68	2.18				A.	ary, 1891. (See Jour. Soc. Chem.
Old deposit		40.70	25.40	32.28	.45	1.17						95.24	1.33	3.43				A.	Ind., January, 1895.)
Independence group:																			
New York	149	53.02	.33	36.80	3.81	6.04						78.86	8.20	12.94				S.	Surface sample.
Do	150	36.66	39.05	17.87	2.94	4.48						70.66	11.62	17.72				S.	Sample from 4 inches depth.
Do	151	47.58	9.67	40.86	.77	1.12						95.58	1.80	2.62				S.	Sample from 4 to 12 inches depth.
Wilmington	152	51.99	9.14	21.42	2.90	14.55						55.14	7.47	37.42				S.	Deposits along shore of lake.
Do	153	55.10	.74	42.34	.28	1.54						95.80	.60	3.60				S.	Deposits from bottom of lake.
Do	154											24.40	17.71	57.89				S.	Lake water; specific gravity 1.104.
Wilkesbarre			9.23									39.04	1.83	59.00				R.	Dried sample.
Omaha	79	36.67	.97	25.88	4.83	26.83					4.82	41.51	7.74	43.02			7.73	S.	Surface sample.
Do	78	45.21	.71	6.85	.05	47.18						12.67	.09	87.24				S.	Salt from surface to 10 inches depth.
Do	77	49.97	19.04	2.94	1.50	26.55						9.49	4.84	85.67				S.	Salt from 10 to 14 inches depth.
Do	76	53.17	18.29	4.66	1.16	17.31					5.41	16.36	4.05	60.62			18.97	S.	Salt from 14 to 17 inches depth.
Do	148	39.46	30.30	11.25	.95	18.04						37.20	3.14	59.66				S.	Salt from 2 feet depth.
Berthaton	80	51.21	7.01	15.61	2.63	21.00					2.54	37.36	6.30	50.26			6.08	S.	Surface sample.
Do	81	53.87	3.06	14.75	2.66	59.55						34.27	6.16	59.57				S.	From large lake and from best product of deposit.
Do	84											20.44	13.84	65.72				S.	Solution from upper lake.
Gill		1.61		94.50	.54			2.52										R.	Undetermined and loss 0.83.

[a] Numbers used by E. E. Slosson in Bull. Wyoming Exper. Sta. No. 49.

[b] S., E. E. Slosson; P., H. Pemberton and G. P. Tucker; A., D. H. Attfield; R., L. D. Ricketts.

UTILIZATION.

Thus far the utilization of the natural sulphate of sodium for the manufacture of sodium compounds has not been entirely successful in Wyoming, owing to the difficulty encountered in liberation of the water of crystallization. In 1885 the Laramie Chemical Works erected an alkali factory to manufacture carbonate and caustic soda out of the natural material. The plant was equipped with large reverberatory furnaces with small iron pots sunk in the floor. During the experimental stages it was found that this method was too expensive. Experiments conducted at the State University discovered a cheaper method of driving off the water from the natural product; but the results of these experiments have not been applied in a commercial way. The plant was compelled to close down in the late nineties, as it could not successfully compete with alkali manufacturers of the East, owing to the high price of labor. The crude soda from the Union Pacific Lakes near Laramie was converted at the Laramie Chemical Works into marketable products, as caustic soda, salt cake, soda ash, and concentrated lye. During six months in 1885 a total of 35 tons of caustic was produced, and in 1887 this plant manufactured approximately 4,000 pounds of salt cake, 4,800 pounds of concentrated lye, 8,000 pounds of caustic soda, and 16,000 pounds of soda ash. In 1892, 1,670 tons of salt cake were shipped from Laramie. Later the salt was dried and utilized for glass making, some of it being shipped to glass plants in the East. Considerable quantities of soda, obtained from the Union Pacific Lakes, were used by the Laramie Glass Company, which was organized in 1887 and began the manufacture of window glass the same year. At first pot furnaces were used, but these proved unsatisfactory and were soon replaced by furnaces similar to those used at the Rock Island (Ill.) and other eastern glass factories.

In obtaining the soda for the chemical works and the glass plant the purest soda crystals from the surface were scraped up when the lake was dry and kept in large heaps in the open air while being worked up. The outer layer of such a heap loses, of course, its water of crystallization and becomes white powder, but at a depth of an inch or two the crystals are entirely unchanged. Good crystals have even been found in the interior of a small heap of soda that had been exposed to the weather for over six years. The chief impurities are magnesium and calcium salts and chlorides. The average output is, however, as pure as the commercial "salt cake" made by the Le Blanc process, which usually contains 93 to 95 per cent of sodium sulphate. The sulphate from the lakes contains more magnesium salts than the Le Blanc sulphate, but on the other hand it is freer from iron and therefore better suited for glass making. In the works at Laramie the soda was dried by methods in imitation of the old Le Blanc process, which involved useless labor and expense. According to analyses made in 1891 in the Wyoming experiment station laboratory the final product was less pure than when it was put into the calcining furnace. It is not at all necessary to use the high heat of the Le Blanc process, because the water of crystallization is entirely driven off at a temperature a little above 212° F., or the sodium sulphate can be precipitated in anhydrous form from a hot solution without difficulty. The application of a few elementary chemical principles to the problem would have saved many thousand dollars that have been wasted in the attempt to utilize the soda deposits of the Laramie Plains. In recent years nothing has been done with the crude material in a commercial way. The Syndicate Improvement Company erected a soda plant in 1892 on its soda deposits in Sweetwater Valley, near Independence Rock, in southwestern Natrona County. Operation was begun on the Berthaton claims and after the erection of the soda plant the company commenced to manufacture bicarbonate of soda, but was unsuccessful in the manufacture of any of the soda compounds, and in a short time the plant was shut down. The cause of failure was not learned. There seems to be no apparent reason why the valuable deposits of soda found in these lakes can not be made to take the place of a large amount of the imported product.

The Wyoming deposits of sulphates and of the mixture of the sulphate and carbonate of sodium are of considerable interest and importance on account of the large amounts in which they occur, their purity, and the fact that there is a large market for such material where facilities for placing it on the market are available. Much of the Wyoming sodium sulphate needs only to be dried to furnish a superior grade of the salt cake of commerce, elsewhere obtained as a by-product in the manufacture of common salt. The mixture of the carbonate and sulphate when dried furnishes a cheap raw material from which soda ash, caustic soda, salt cake, concentrated lye, and various other sodium salts may be manufactured. In many localities this mixture is supplanting sodium carbonate in the manufacture of glass. It would seem that the sulphate deposits ought to be one of Wyoming's valuable resources, although at present none of these deposits are utilized at any place in the State.

Besides the surface alkali deposits or so-called soda lakes there are numerous soda springs scattered throughout Wyoming and at many of them the waters are so highly charged with alkali that they build up considerable deposits around the spring and along the valley or flats over which the water flows. These springs and soda deposits are too numerous to describe further. Like the spring waters, much of the well water throughout the State contains a large amount of alkali salts. A notable example is the water of the wells at the city of

Green River. As the salts obtained from these wells are at present placed on the market, a short description of the wells and the process of manufacturing the commercial product will be given.

GREEN RIVER SODA DEPOSITS.

In some respects the Green River soda deposits are somewhat similar to the "soda lakes" of the Independence group in Sweetwater Valley, southwestern Natrona County. Both contain large quantities of sodium carbonate and apparently derive the salt from the shales of the Green River formation. This source of the soda is further suggested by the fact that numerous springs which rise from these shales at various places in the Red Desert of Wyoming show considerable sodium carbonate in the water. The Green River sodas, however, differ decidedly from the sodas in the Independence alkali group in the absence of sodium sulphate. The well waters at Green River show only traces of sulphates, but in the sodas of the Independence alkali group sodium sulphate is present in considerable quantities. The first well (No. 1[a]) drilled on the Green River bottoms was a prospect well put down by the Green River Fuel and Oil Company, in which most of the citizens of Green River were interested. This well was drilled in 1896 to a depth of 692 feet. For the first 500 feet it was an 8-inch hole; for the remaining 192 feet a 6-inch hole. A flow of alkali water was struck at a depth of 125 feet. Below this the hole was dry to a depth of 685 feet, where artesian water was encountered in a white sandstone in the Wasatch formation and furnished a small flow at the surface. Although the quality of the water was known, nothing was done in the way of marketing the soda until some time afterward. In 1899 the title to this well reverted to B. Spinner, who owned the land.

In the winter of 1896–97 the Waters well (No. 2), an 8-inch hole, was drilled to a depth of 200 feet, and in April, 1897, the Spinner well (No. 3), a 6-inch hole, was drilled to a depth of 354 feet. In both wells soda was encountered at 125 to 200 feet below the surface.

In 1902 Mr. Spinner sold the old Green River Fuel and Oil Company's well and 40 acres of land to the Western Alkali Company. In 1903 this company drilled its first new well (No. 4), on the ground where the sal-soda plant was located. This was an 8-inch hole and went to a depth of 720 feet. In this well, as in well No. 1, artesian water was struck at about 685 feet. Both wells produced good soda in the first 200 feet and were cased by the company to be used permanently. Both wells, however, were finally abandoned because of defective casing. Another well (No. 5), put down to a depth of 705 feet, entered the same sand and supplied the same kind of water as the two wells just mentioned and was later abandoned for the same reason. Near

[a] Numbers refer to corresponding numbers in figure 50.

the soda plant a shaft had been sunk to a depth of 114 feet. From the bottom of this shaft an 8-inch hole (No. 6) was drilled to a depth

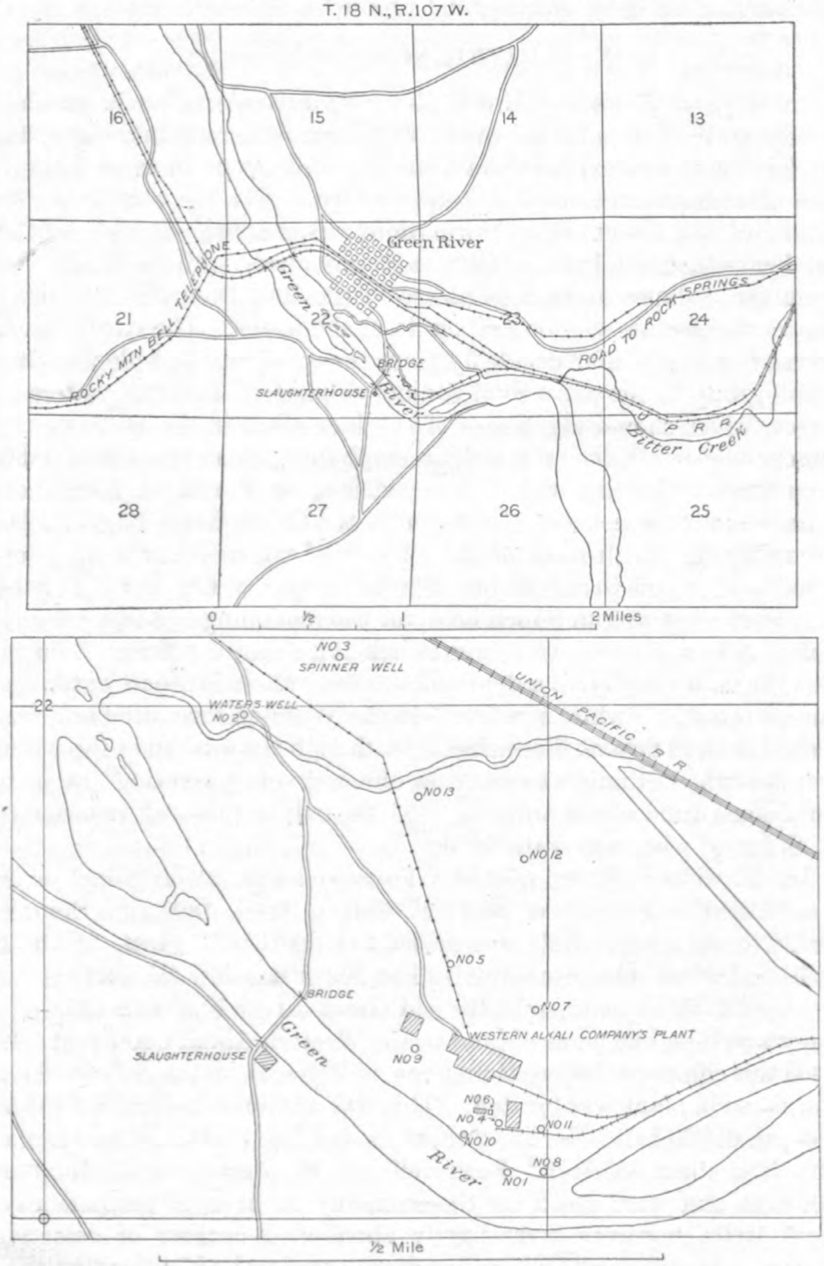

FIGURE 50.—Map showing location of Western Alkali Company's soda wells at Green River, Wyo.

of about 200 feet and yielded a good quantity of soda; this well is still in use. Seven other wells have been drilled by the Western

Alkali Company during the past few years within an area of 2 acres. They range in depth from 150 to 300 feet and are 8 inches in diameter. The last well (No.13) put down by the company was drilled in October, 1909, to a depth of 180 feet. Most of these wells produce good soda. There is considerable variation in the soda content of the water in the wells thus far drilled. The following features are common to all the wells: The wells must be cased from 65 to 100 feet in order to keep out the surface water; the soda belt ranges from 100 to 300 feet and apparently ceases below that depth; the artesian-water stratum, a fine grayish-white sandstone in the Wasatch formation, lies approximately 380 feet below the base of the soda belt or 680 feet below the surface of the water in Green River at Green River station. The location of the Western Alkali Company's wells is shown on the accompanying map (fig. 50).

The deepest well in Green River was drilled by the Sweetwater Brewing Company in November, 1909. Soda was encountered at the same horizon in this well as in the Western Alkali Company's wells, but no analysis was made of the water. The artesian-water stratum was struck at a depth of 765 feet and furnished a good flow of water with a pressure of 43½ pounds at the surface of the ground. This well is about half a mile from the old Green River Fuel and Oil Company's well. The formation penetrated in both of these wells is identically the same and the water encountered in the "soda belt," as well as the artesian water, is approximately of the same character in the two wells.

Mr. Hugo Gaensslen, general manager of the Sweetwater Brewing Company, has furnished the following statement concerning the well:

Well is 780 feet deep, 10 inches in diameter for the first 190 feet, and cased that deep with 8¼-inch casing; balance of the way the well is not cased and is 8¼ inches in diameter. We did not keep an accurate log of the well for the reason that we knew practically what we had to contend with from knowledge acquired from wells the Western Alkali Company drilled. First 10 feet is surface soil; then a gravel bed of about 10 feet; and after that all the way down there is practically a solid bed of what we call shale, which stands up without casing. At about 150 feet we encountered a little water which was unfit for our use, which, however, we did not have analyzed and which we have cased off as stated above; balance of the hole was dry. Water of a fair flow, about 400 gallons per hour, and of a useful quality, was encountered at 765 feet, after going through about 2 feet of what appeared to be sandstone. Water comes from a sand bed, white, which we punched through for 15 feet and quit. Have not had water analyzed, but are using it about the brewery for boilers, condense water, and for cleaning and scrubbing. It is quite soft and the first two weeks was a good drinking water. We think, however, that some of the surface water is mixing with the lower flow and we intend, therefore, this summer to case the well down to the bottom and shut off everything above the water coming from the sand bed. This is the deepest well at Green River and no coal was encountered. The shale is practically of even hardness, as indicated by the drilling operations, but varies in color; it is of different tints, gray, yellow, blue, brown, green, up to almost black. A little gas was encountered about 120 feet down.

During the fall of 1909 only a part of the Western Alkali Company's wells were pumped. Three of the wells were supplying water the day the writer visited the plant. The company at this time was testing the wells to ascertain the effect of continuous pumping on the amount of salt or mineral held by the water and what interference, if any, there was between the various wells. Although a complete chemical test had been made of the waters from the separate wells, showing the variation in the salt content under various conditions over a period of several months, the company was not willing to supply any of this information and no conclusions concerning these results can be given here. It should be borne in mind, however, that conditions at the several wells are very different and give a wide range in results. Continuous pumping at some of the wells does not materially decrease the amount of salt in the water, but at other wells a few hours' pumping shows a remarkable decrease in the mineral content. In general there is a decrease in the quantity of salt held in solution as pumping continues, but if the well is allowed to stand idle for some time the water gradually regains its mineralization. Some wells recover their normal amounts of salt much more rapidly than others, and there is considerable difference in the mineral content and composition of the water at the different wells. The amount of water available from any well also depends in part on the treatment of the neighboring wells. It is reported that if only one is pumped the yield is greater for that well than when several wells are pumped at the same time. The deduction that these detailed facts would warrant can not be given here, as the company does not care to make its records public at the present time. The general range of mineralization of these waters in regard to the two chief minerals was given as follows: NaCl, 400 to 1,800 grains in a United States gallon; Na_2CO_3, 2,000 to 6,000 grains in a United States gallon. These values should be considered as maximum and minimum rather than averages.

In 1896 the Green River Fuel and Oil Company, while drilling its prospect well No. 1 at Green River, encountered a flow of alkaline water at a depth of 125 feet. A sample of this water sent to the University of Wyoming at Laramie proved to be a nearly saturated solution of sodium carbonate of greater purity than any found elsewhere in the State. On standing a few days a thick deposit of large crystals of hydrous sodium carbonate (sal soda) filled the bottom of the vessels. The salt thus formed was much purer than the commercial product and contained only traces of chlorides and sulphates. The water contained 8.9 per cent of sodium carbonate or 24 per cent of crystallized sal soda. It was reported by Robert Morris, of Cheyenne, that when 60,000 gallons was pumped from this well in twenty-four hours it lowered the well only an inch or two and did not appreciably lessen the strength of the soda solution. Not all the wells furnish so much sodium carbonate. A sample of the product of evaporation from one of the wells drilled at a later date gave the following results: Sodium carbonate (anhydrous), 48.2 per cent; sodium chloride, 51.6 per cent; undetermined, 0.2 per cent, with traces of magnesium and sulphates. According to another analysis, made by Herman Harms, of Salt Lake, the water shows a specific gravity of 1.10 at 59° F. and contains 246 grams of sodium carbonate crystallized and 6.12 grams of sodium chloride per liter.

Analysis of the Green River soda made by G. C. Wheeler, of Chicago, shows by the absence of any appreciable quantities of sulphates that this soda differs decidedly from all other waters and alkali deposits in the State. The analysis is as follows:

Analysis of Green River soda.

Silica	0.51
Iron and aluminum	.42
Calcium	.64
Magnesium	.27
Insoluble residue	.23
Water	22.57
Anhydrous carbonate of soda	75.36
	100.00

MANUFACTURE OF SODA AT GREEN RIVER.

SAL-SODA PROCESS.

The water is pumped from all or part of the wells by means of electric motors and carried in pipes to the main building, where the water from the separate wells is run into the same tank and allowed to mix. There are three large evaporating tanks that are used in turn as demand requires. The water is allowed to stand in the evaporating tank, which is provided with pipes through which steam is passed to facilitate evaporation, until the solution reaches the desired concentration. The concentrated solution is then run through pipes to one of the ten crystallizing vats, arranged in two parallel rows of five vats each, in an adjoining building, where it is allowed to cool until the crystallization is completed. The liquid residue is then run back into the "causticizers" in the main building and used in making caustic. The crystals are taken from the crystallizing vats and placed on drying tables, where they soon lose their crystalline form, breaking down into a fine white powder. This powder is then packed in 100-pound boxes and shipped to the eastern and western markets.

CAUSTIC PROCESS.

In the manufacture of caustic the water pumped from the wells, as well as the remaining water from the sal-soda crystallizing vats, is run into one of the two "causticizers" in the west end of the main building. These "causticizers" consist of large circular tanks 12 feet in diameter and 10 feet deep in which are perforated vessels containing caustic lime. Around these vessels the solution of sodium carbonate is agitated, and after "causticizing" the liquor is passed through four rectangular filters or iron settlers, where most of the lime is separated. The reaction is based on the fact that calcium carbonate is insoluble and that sodium carbonate and sodium hydroxide are soluble ($Na_2CO_3 + Ca(OH)_2 = 2Na(OH + CaCO_3)$).

The liquor after passing through these filters or iron settlers is allowed to stand for some time in the vat or settling tanks in order to let the finer particles of $CaCO_3$ settle. The upper part of the clear liquor is then let into a drum by vacuum and run into one of two storage tanks, 12 feet deep and 20 feet in diameter, where the liquor is allowed to stand for some time in order that all the remaining finer lime particles may settle. From these two tanks the clear liquor is drawn by vacuum into a third storage tank or settler, 12 feet deep and 20 feet in diameter. The liquor is now practically free from lime and the clear liquor from the third tank is run into one of the three salt settling pans, where waste steam heat is used to aid the evaporation of the solution and the settling of the salt as well as of part of the sulphur. From these salt settling pans the slightly concentrated liquor is run through two steam-heated low-pressure boilers, where further concentration takes place and the moisture is removed. The first boiler maintains a vacuum of 7 inches of mercury; the second a vacuum of 21 inches of mercury. From these boilers the concentrated liquor is run into a storage tank in the upper part of the building, and thence to the "end pots," large cast-iron pots set directly over a furnace, where all the remaining traces of water are driven off at a low red heat. The hydrate at this stage is as a rule nearly black. Sometimes small quantities of niter are added to the fused mass in order to whiten it. The hydrate is ladled from the "end pots" into sheet iron vessels or drums and shipped to Denver and other western cities.

PRODUCTION.

The Western Alkali Manufacturing Company produced in 1909 approximately 100 tons of caustic and 150 tons of washing soda.

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SURVEY PUBLICATIONS ON SULPHUR AND PYRITE.

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MISCELLANEOUS NONMETALLIC PRODUCTS.

MICA DEPOSITS OF NORTH CAROLINA.

By DOUGLAS B. STERRETT.

INTRODUCTION.

The extensive commercial applications of mica have placed it among the important mineral products of the world. In value of production mica does not rank high as compared with certain other mineral products, though its properties render it indispensable in several important industries. The world's supply of mica is drawn chiefly from India, Canada, and the United States, with smaller amounts from Ceylon, southwest Africa, and Brazil. In the United States mica deposits have been found in about 20 States. The most important producers among these have been North Carolina, South Dakota, New Hampshire, Virginia, Colorado, New Mexico, Alabama, Georgia, and Idaho. For many years North Carolina has led in both quantity and value of output and during some years has furnished over half of the total production. The value of the mica production of the United States during 1908 was $267,925, and of this amount North Carolina is credited with $127,870. The value of the mica production in North Carolina during 1907 was $225,206, the total for the United States being $392,111.

Mica is used in various industries, such as the manufacture of electrical machinery, stoves, certain forms of lamp chimneys, fireproof materials, wall papers, lubricants, etc. The perfect insulating qualities of mica and the adaptability of its sheets to various forms of manufacture render it unsurpassed for use in electrical apparatus. By fitting together and cementing with shellac many small thin sheets, mica is built up into large sheets of "micanite" or "mica board," suitable for many forms of electrical insulation. The transparency, flexibility, and resistance to heat of mica are qualities that make it particularly suitable for use in stove windows and lamp chimneys. When ground, mica is used to impart a silvery luster to wall paper and for other decorative effects. Ground mica is also mixed with oils and grease for lubricating purposes. When mixed with shellac, ground mica is used in various types of electrical insulators under the term "molded mica."

The information for the present paper has been obtained at various times during the last five years in the course of work for both the United States Geological Survey and the North Carolina Geological Survey. The greater part of the mine descriptions were obtained during 1905, 1906, and 1907 and represent typical deposits in all those counties in which mica mines have been examined by the writer. A large number of other descriptions have been prepared also, which it is hoped will be used in a later report by the State Survey. The brief notes on the general geology of the region and on the mica deposits are largely taken from an earlier paper,[a] in which the occurrence of mica-bearing pegmatites and their origin were treated, rather than commercial mines.

A number of the mica deposits of North Carolina were opened in prehistoric times by aborigines. Some of these operations have been described in the early days of mica mining by white people, and several of the deposits where such work was done are described below. The present period of mica mining was begun in 1867 by L. E. Persons, of Philadelphia, previously of Vermont. Mr. Persons's attention was directed to Jackson County by someone in Philadelphia who had seen a crystal of mica exhibited at the state fair in Columbia in 1858 by D. D. Davies, of Webster. In the fall of 1867 Mr. Persons went to Jackson County and learned from Mr. Davies the location of favorable prospects for mica in Jackson and Haywood counties, which he soon opened.[b] Shortly after this the mica industry began in Yancey and Mitchell counties with the opening of the Silvers mine by Thomas L. Clingman.

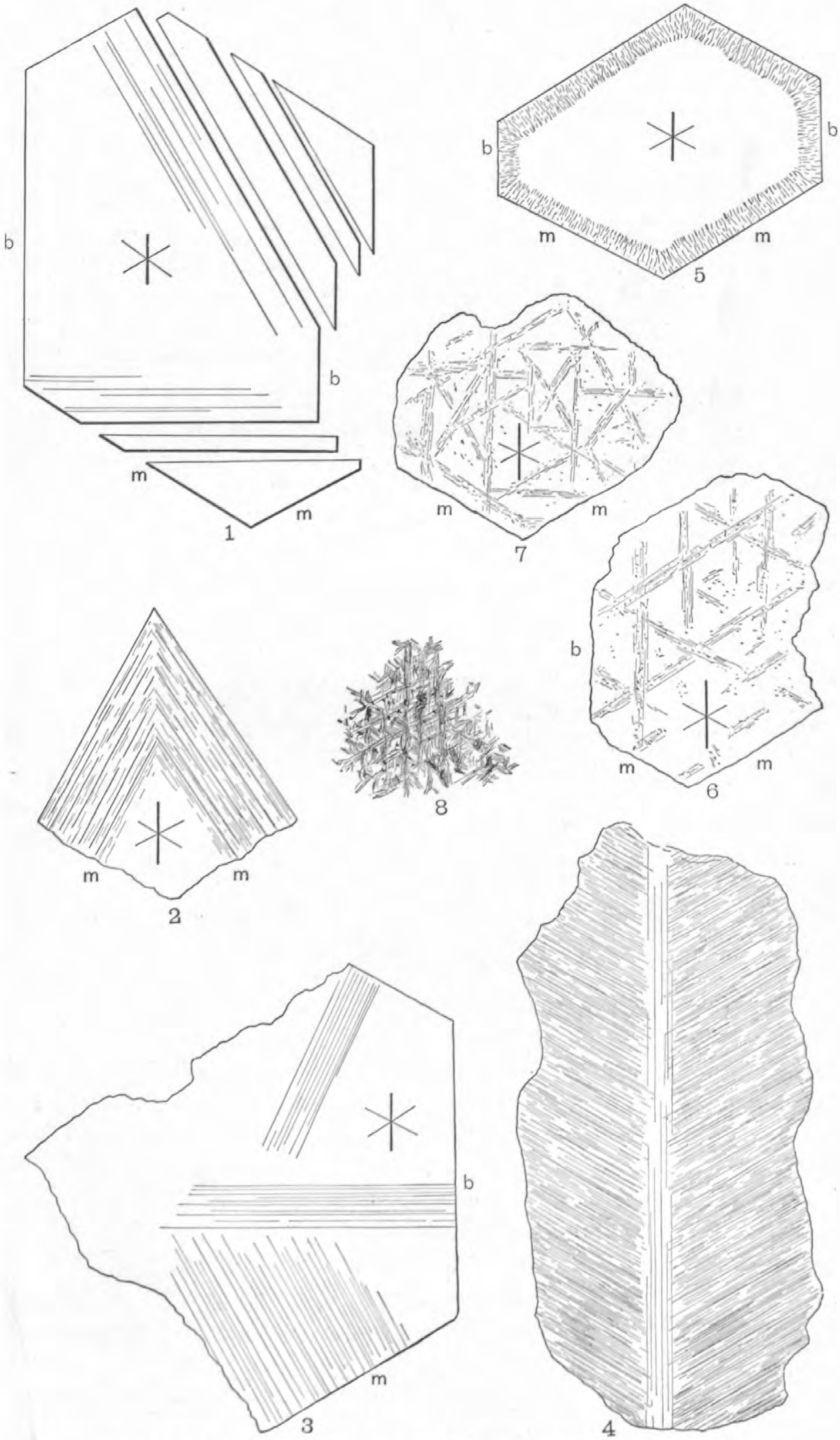
CHARACTERISTICS OF MICA.

Of the numerous varieties of mica there are but four that have commercial value. These are muscovite, phlogopite, biotite, and lepidolite. Muscovite and phlogopite have a wide application in both sheet and ground form. Biotite has only recently been used in the ground form. Lepidolite is used as a source of lithia salts and to a small extent for ornamental purposes. Muscovite is the only mica that has been mined extensively in North Carolina, and it is only within two years that a small demand has arisen for biotite for grinding.

Muscovite, like all the other micas, belongs to the monoclinic system of crystallization and has a symmetry approximating the hexagonal.

[a] Mica deposits of western North Carolina: Bull. U. S. Geol. Survey No. 315, 1907, pp. 400-422.

[b] This information was furnished by Judge D. D. Davies and Mrs. John L. Richardson, daughter of L. E. Persons, in a certified statement dated March 22, 1907.



SPECIMENS OF MICA OF VARIOUS STRUCTURE.

This symmetry is indicated by the nearly hexagonal outline often observed in the prisms, by the percussion and pressure figures, and by "ruled" and "A" mica, as described below.

Mica mined for commercial purposes is generally found in rough blocks, sometimes with an irregular development of crystal faces. The faces are not usually as many as would be required to complete the simplest figure, and their surfaces are generally very rough. Very commonly a large part, if not all, of a block of mica has a ragged outline without plane surfaces. Occasionally fairly well developed hexagonal or rhombic prisms are observed in crystals of mica weighing hundreds of pounds.

Rough crystals, or "books" of mica, as they are called in the Western States, do not split perfectly until the outer shell of etched and sometimes partly crushed mica has been removed. This is accomplished by rough splitting or cleaving the large book into sheets one-eighth inch thick or less and trimming the edges with a knife held at a small angle with the cleavage. Further splitting is then easy, because the cleavage of mica is so perfect and the tangled outside edges of the sheets have been removed. By grinding a wedge edge on the sheets and using a thin, sharp knife mica can be readily split into sheets as thin as one one-thousandth of an inch or thinner.

A percussion figure is formed by three cracks or cleavages in a plate of mica crossing at a common point and making angles of approximately 60° with one another, commonly described as a six-rayed star. It may be produced by striking a sheet of mica a sharp blow with a pointed punch or thrusting the punch through the sheet. The same thing is produced occasionally on a large scale in a mine by a miner unintentionally striking the cleavage face of a block of mica with a pick. One of the rays, sometimes noticeably more prominent than the other two, corresponds in direction with the front axis of a mica crystal. The other two rays are parallel to the prism faces, *m*. (See Pl. XIV, 1 to 7.)

A pressure figure is very similar in appearance to the percussion figure, but oriented with its rays at angles of about 30° with those of the percussion figure. The pressure figure is seldom obtained with the same symmetrical, perfect development as the percussion figure and is often very difficult to obtain. By pressing with a punch against a sheet of mica one or more rays of the pressure figure may be produced, and if the punch is then thrust through the sheet a percussion figure will also be formed and the two may be seen with their approximate 30° relation to each other.

Mica has a number of physical peculiarities which give rise to different trade names and descriptive terms used by the miners. These are due to crystal structure, color, and inclusions. Structural peculiarities give "ruled" or "ribbon," "wedge," "A," "hair-lined," "fish-bone" or "herringbone," and "tangle-sheet" mica. Trade names for different colors of mica are "rum," "ruby," "amber," "white," and "black." Brown, green, and greenish-brown colors also occur in mica. Certain inclusions give "specked" and "clay-stained" mica.

"Ruled" or "ribbon" mica is formed by more or less clean, sharp parting planes cutting through the mica crystals and making an angle of a little more than 66° with the base or cleavage surface. This parting passes entirely through some crystals and in others extends only part way across the face or does not cut through the entire thickness. (See Pl. XIV, 1.) The trace of the ruling planes corresponds in direction to the rays of the pressure figure in mica. Though a cleavage resembling ruling may be produced by making a series of percussion figures along the line of one of the rays, it is evident that "ruling" planes do not correspond to the lines of weakness represented by the percussion figure, for the two make angles of about 30° with each other. On the other hand, the ruling planes fall in the same directions as the rays of the pressure figure and probably occur along the lines of weakness represented by them.

"Ruling" lines occur more commonly in one series of parallel lines in mica. In some specimens these parting planes are present in two or even three directions, and their traces on the cleavage planes make angles of about 60° with one another, dividing the mica sheets up into small triangular plates. The value of large blocks or crystals of mica, otherwise of excellent quality, is sometimes rendered small or practically nothing by the presence of many "ruled" lines.

In "wedge" mica the crystals are thicker on one side than on the other. The difference in thickness on opposite edges may be greater than half an inch in some crystals 3 inches in diameter. This structure is due to an unequal development in the width of the laminæ. Some of the laminæ extend across the entire width of the crystal, but others do not, and generally they are not matched by similar laminæ extending from the opposite edge. In this way a greater thickness is developed on one side of a mica crystal than on the other. It is not uncommon for wedge-shaped sheets of quartz to be included between the laminæ of such crystals. The "wedge" structure is often associated with the "A" and "fish-bone" structure.

In "A" mica there are two series of lines or striations crossing the sheets at angles of about 60° with each other, whence the term "A." (See Pl. XIV, 2 and 3.) In some pieces these striations are caused by "wedge" structure developed in the mica crystals, with or without the presence of detached swordblade-like strips of mica replacing the sheets that have "wedged" out. In other specimens the striations are caused by small folds or crenulations in the sheets of mica. The "A" striations have the same orientation in the mica sheets as the "ruling" lines; that is, their position corresponds to the rays of the percussion figure. "Ruling" is sometimes present in "A" mica. Where the striations are caused by small folds the mica sometimes splits across them and the sheets have a commercial value, though not as high as perfect plates. Where the striations are due to the "wedging" out of sheets, only plates from between the "A" lines can be used commercially and the value of large crystals is thus materially affected.

In the "fish-bone" or "herringbone" structure striations with or without "ruling" and apparently identical with the "A" lines of mica make angles of about 120° with each other and join along a center line or spine. This gives a structure resembling the skeleton of a fish, as shown in Plate XIV, 4. The "fish-bone" structure is probably caused by a twinning of two crystals of "A" mica, so that one set of striations in each fall together and the other two sets are inclined toward each other and meet at the twinning line. Mica with the "fish-bone" structure has no commercial value as sheet mica, but is used for scrap for grinding.

In "tangle-sheet" mica (a name little used) the laminæ split well over a portion of their extent but tear when split in other parts. This is due, in some places, to the failure of certain laminæ to form perfect sheets and the intergrowth of portions of one sheet with that lying next to it. Such imperfections sometimes extend through half an inch or more of the thickness of a crystal of mica. In this way an apparently sound crystal of mica is rendered of little value or worthless for sheet purposes.

The color words descriptive of mica are self-explanatory, except the "white" and "black" mica of commerce. In speaking of the color of mica the miners or dealers ordinarily consider the color of sheets a sixteenth of an inch or more in thickness. Such colors as "rum," "ruby," "green," etc., observed in the thicker sheets of mica, practically disappear when the mica is split into thin sheets for trade purposes. The mica is then called "white" mica to distinguish it from phlogopite or "amber" mica. By "black" mica is generally meant muscovite "specked" with magnetite, as described below, but in some cases dark-brown to black biotite is also called "black" mica. "Rum," "ruby," "green," and the lighter-colored micas make the best grades of "white" mica for the glazing trade. Dark-brown and brownish-green mica has to be split much thinner than "rum" mica to gain the desired transparency and is therefore generally classed as "No. 2," even when flawless and clear.

Some muscovite shows color variations arranged in accordance with the crystal structure. These more commonly appear in zonary bands following the crystal outline. Thus, to one looking through the sheets there may appear a center of dark "rum" color with a fringe of light "rum" or yellow surrounding it and possessing a hexagonal or rhombic outline; or the center may be light colored and the border zone dark, as in Plate XIV, 5. In some sheets there are alternations of bands of varying color. Such color variations generally entirely disappear when the mica is split into sheets of the thickness required by the trade.

The pleochroism of mica is strong and may be well observed in small crystals with prism planes sufficiently smooth to transmit light. It will be found that crystals of such mica viewed edgewise are far more transparent than sheets of the same thickness. The color is also quite different in these two views.

Muscovite containing inclusions between the laminæ of spots or particles of different-colored minerals is called "specked" and sometimes also "black" mica. Magnetite is the most common inclusion between the laminæ and occurs as black to brown dendritic tufts arranged in definite lines or patterns corresponding to the crystal structure of the mica or scattered irregularly through the sheets. These tufts of magnetite are very thin and rarely penetrate appreciable thicknesses of mica. The dark-brownish color of many of these spots is due to the translucency of the thin films of magnetic iron. The arrangement of the streaks of spots in the mica is in some cases parallel to the direction of the rays of the percussion figure (Pl. XIV, 6) and in others apparently parallel to the rays of the pressure figure (Pl. XIV, 7). Each spot owes its dendritic appearance to the arrangement of still smaller particles of magnetite in lines following, in some cases at least, the rays of the percussion figure. (See Pl. XIV, 8.) From these lines of particles other particles branch off at more or less definite angles. By decomposition the magnetite is sometimes partly or entirely altered to hematite or limonite and the "specks" become red or yellowish brown. In this way striking patterns in colors are produced, which give rise to the name "hieroglyphic" mica and which were once thought to be the inscriptions of the aborigines.

In the zone of surface weathering, and principally within a few feet of the surface, mica crystals are sometimes "clay-stained." This is due to the working in of clayey solutions between the laminæ. The solutions penetrate large areas of some crystals and work in between many of the laminæ, greatly damaging the value of the mica.

"Specked" or "clay-stained" mica has little if any value in the glazing trade, though either can be used in electrical manufacture. Their application even in the latter industry is less extensive than that of clear or "white" mica. Mica with "specks" of magnetic iron is not satisfactory for insulation where electric currents of high potentiality are used, because the "specks" tend to weaken the insulating qualities by acting as lines of less resistance.

Occasionally crystals or sheets of biotite are included in the muscovite crystals, or vice versa. In such a case the two micas generally occur in parallel intergrowths and have a common cleavage plane. Large crystals of muscovite sometimes inclose smaller ones with no definite orientation. The cleavage of the included crystal is generally inclined or at right angles to that of the host.

DISTRIBUTION OF DEPOSITS.

Mica deposits have been opened in 18 or more counties in western North Carolina. The deposits occur in an area nearly 75 miles wide and 200 miles long, extending in a northeast and southwest direction through the State. (See fig. 51.) For convenience this area may be divided into three belts—the Cowee-Black Mountain belt, the Blue Ridge belt, and the Piedmont belt. The Cowee-Black Mountain

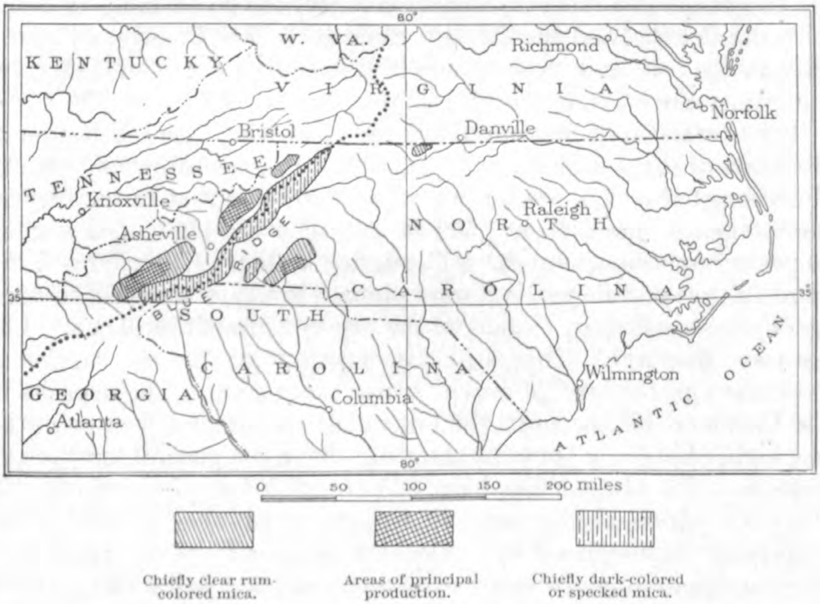


FIGURE 51.—Map showing areas in North Carolina in which mica has been mined.

belt extends nearly through the State, parallel to and near its northwest border. It lies northwest of the Blue Ridge and includes part of Macon, Jackson, Transylvania, Haywood, Buncombe, Yancey, Mitchell, Watauga, and Ashe counties. The Blue Ridge belt follows the Blue Ridge through the State and extends several miles to the southeast among the foothills. It is of small importance compared to the other two. Mines have been opened in Jackson, Transylvania, McDowell, Caldwell, and Wilkes counties in this belt. The Piedmont belt lies in the Piedmont Plateau and its small mountains, southeast of the Blue Ridge. Mica mines have been worked in Rutherford, Burke, Cleveland, Gaston, Lincoln, Catawba, and Stokes counties of this belt. Mica deposits of commercial value have not been found in unbroken succession in any of these belts.

The quality of mica obtained from different localities varies considerably, though in a single belt or in adjacent portions of the same belt the quality is commonly very similar. In general, the mica of the Cowee-Black Mountain belt is clear and of a light color (as a rule "rum"). That from the Blue Ridge belt has a dark smoky-brown or greenish-brown color and much of it is more or less "specked." In a large part of the Piedmont belt, especially in Cleveland, Gaston, and Lincoln counties, the mica is of good quality and similar to that of the Cowee-Black Mountain belt. There are exceptions to these characteristics, in part connected with geologic conditions, such as the presence or absence of granite near by. Most of the mines described below are in the Cowee-Black Mountain belt. Exceptions are the Rochester mine in Jackson County, the Reed mine in Transylvania County, and the Triplett mine in Wilkes County, all in the Blue Ridge belt, and all the mines in Rutherford, Cleveland, Lincoln, and Stokes counties, in the Piedmont belt.

The Cowee-Black Mountain and the Blue Ridge mica belts are in the heart of the Appalachian Mountains. The deposits lie at various elevations between 1,500 feet above sea level and that of the highest mountains, or more than 6,500 feet. Some are high upon rugged slopes or summits where the soil covering is thin. Others are on the gentle slopes of valleys, or former plateau levels or terraces, covered by deep residual clays. Many of the deposits present ideal conditions for mine drainage. This is an important point, for the rainfall is excessive and the level of ground water is not deep. The deposits in the Piedmont belt occur in the low but locally steep ridges or in the few higher hills or mountains standing above the general level of the plateau. The plateau lies from 800 to 1,500 feet above the sea in the mica region and is more or less dissected by river and creek valleys 200 to 300 feet deep. The sky line seen from any prominent ridge is approximately level, with mountains or peaks rising above it at intervals. The problem of mining mica from deposits in the Piedmont belt is often difficult on account of their occurrence in hills with but slight elevation and gentle slopes, so that natural drainage can not be readily secured.

GENERAL GEOLOGY.

The mica deposits of North Carolina have been found in highly metamorphic rocks, probably all of Archean age. These rocks are mica, garnet, cyanite, staurolite, hornblende, and granite gneisses and schists. Other rocks occurring in the region, also of Archean age, are granites, diorites, and peridotites, with their derived soapstones and serpentines. Younger granites, volcanic rocks, diabase, and sediments occur in parts of the region. The folding, faulting, mashing, and recrystallization of the gneisses and schists have been so extreme that it is often difficult to determine the original igneous or sedimentary nature of the formations.

The major part of the mica deposits occur in two formations, as mapped by Keith[a]—the Carolina gneiss and the Roan gneiss. The Carolina gneiss includes most of the gneisses and schists mentioned above that are not hornblendic in composition. The Roan gneiss is composed of hornblende gneiss and hornblende schist with smaller beds of mica gneiss and mica schist included. In the mica region by far the most important formation is the Carolina gneiss. This formation is also the oldest in the region and is intruded by younger igneous rocks, as hornblende gneiss and schist, peridotite, granite, granite gneiss, and diabase. Beginning with the Carolina gneiss the formations have been gashed and cut by the later igneous rocks into irregular-shaped masses, in many places forking out into long tongues or occurring as long, narrow streaks in the intrusives, or vice versa. The diabase rocks are probably of Triassic age and cut across the strike of the older formations in long, narrow dikes. The Carolina and Roan gneisses have been interbanded with and cut at all angles by numerous streaks of granitic or pegmatitic material. These range from a fraction of an inch upward in thickness and locally pass into mica-bearing pegmatites. In some places this pegmatization is so thorough that mica gneisses become strikingly like granite gneisses.

OCCURRENCE OF MICA.

Mica deposits of commercial value in this State are confined to pegmatites. These rocks vary considerably in form, some being typically lenticular in shape and others more or less persistent in length. The lens-shaped bodies are generally conformable with the schistosity of the inclosing rock. They may lie in the same line of bedding or schistosity and be connected by smaller streaks or stringers of pegmatite, or by mere seams in the rock. Many of them, on the other hand, lie in planes of schistosity more or less separated from one another and form parallel or overlapping bodies. In cross section some of these lenses are short and bulky, with a length only two or three times the thickness; others are long and tapering and may constitute simply a bulge in a sheet of pegmatite. In many places the schistosity of the inclosing rock bends around the lenses.

Some of the more persistent pegmatites occupy straight fissures that hold their direction for a considerable distance. Elsewhere they are folded with the country rock or bent and twisted into various shapes. Many are more or less conformable with the bedding of the gneisses and schists. In that case they are in large measure subject

[a] Cranberry (No. 90), Asheville (No. 116), Mount Mitchell (No. 124), Nantahala (No. 143) Pisgah (No. 147), and Roan Mountain (No. 151) folios, Geol. Atlas U. S., U. S. Geol. Survey.

to the deformations of the country rock. In many places, however, the pegmatites are conformable for some distance and then branch out, cutting from one layer to another across the bedding. Locally there is an elbowing or bulging out on one wall, without a similar irregularity on the other wall of the pegmatite. It is not uncommon for pegmatite masses to cut across the country rock for long distances.

Though pegmatites have been worked for mica in regions of hornblende gneiss and hornblende schist, where they are directly associated with those rocks, most of the deposits are found in small biotite gneiss or schist masses included in the hornblende areas. Where the pegmatite is in contact with hornblende gneiss, the latter may be highly biotitic.

Pegmatites occur in irregular masses, streaks, lenses, augen, or balls, some of them having no visible connection with other pegmatite bodies. They range from a fraction of an inch up to many yards in thickness. The limit of size below which they can not be profitably worked for mica might be placed arbitrarily at 1 to 2 feet for rich and regular "veins." In the very large pegmatites the mica is not, in general, evenly distributed through the mass, but is richer in one portion than another, so that the entire bulk of the rock does not have to be removed in mining. The irregularities of pegmatites and the consequent difficulties in mining mica from them are well illustrated in road cuts or similar excavations, where pegmatized gneiss or schist has been exposed. The lenticular shapes, pinching and swelling, crumpling, folding, and faulting to be observed in these cuts are found to be nearly duplicated in larger pegmatites opened for mica. As stated before, these smaller masses may grade into those containing mica of commercial value. Here and there the two can be seen at the same locality.

Horses, or inclusions of wall rock, are common in pegmatite. Some of them are in the form of bands or sheets parallel to the walls, and the schistosity of these bands is also parallel to the walls. They range from an inch or two up to several feet in thickness, and their length may be many times their width. Elsewhere they occur as irregularly shaped masses, from a few inches up to several feet thick. If the bedding has been preserved, it may lie at any angle with that of the inclosing wall rock. In some places the horses are partly pegmatized by streaks of pegmatite ramifying through them and by the development of considerable feldspar and quartz through their mass. In such places no sharp line can be drawn between the pegmatite and the original horse.

Pegmatite is closely allied to granite in composition. As in granite, the essential constituents are feldspar and quartz, with more or less mica and other accessory minerals. Though hornblende is rather a common mineral in granite, it is less so in pegmatite. Orthoclase and microcline are the most common varieties of feldspar found in pegmatite. In many places, however, a variety of plagioclase, either albite or oligoclase, makes up part or all of the feldspar component. The feldspar occurs in masses and rough crystals, some of them with a diameter of several feet.

Quartz assumes various forms and positions in the pegmatite. In many places it bears much the same relation to the feldspar and mica as in granite, the three minerals being thoroughly mixed with one another; but the individual grains are many times larger than in ordinary granite. Not uncommonly the quartz and feldspar assume a graphic granite texture in a portion of the pegmatite. Another common feature is the occurrence of large separate masses of quartz occupying various positions in the pegmatite. Such quartz masses may be irregular in form and but little influenced by the shape of the pegmatite or inclosing wall. Many of them, however, lie in bands or sheets parallel to the walls. There may be one or more of these quartz bands constituting varying proportions of the pegmatite. Their thickness ranges from a fraction of an inch up to 6 or more feet. Many of them are lenticular in shape, the length varying from four or five to twenty or more times the thickness. In numerous places these quartz streaks or veins are persistent through the whole length of the pegmatite exposed. Some inclose feldspar or mica bodies; others do not. The quartz of these segregations is massive and generally granular, though locally crystallized. If crystallized it may be translucent or clear and of a dark smoky or light color. It is generally rather pure and does not contain feldspar or mica in appreciable quantity.

Muscovite is the common mica of pegmatite and is the only variety mined in North Carolina. Biotite occurs in moderate quantity in a few deposits, and in smaller amount in many others. Where muscovite and biotite occur together in a deposit, the muscovite is generally clear and of good color. Again, mica from deposits in rock formations where the ferromagnesian minerals are abundant, such as hornblende or biotite gneiss and schist, is generally found to be clear and of light color. Where the pegmatite is closely associated with or occurs in granite with a paucity of the ferromagnesian minerals, the mica is generally of dark color and much of it is "specked."

The mica occupies various positions in the pegmatite. Where the rock has a typical granitic texture the mica may be found evenly distributed through it. More commonly the larger crystals will be found either in clusters at intervals through the "vein," in places connected by streaks of small crystals, or collected along one or both walls of the pegmatite, with some of the crystals partly embedded in the wall rock. Where there is a quartz streak within the pegmatite, the mica occurs on either or both sides of it. The mica may be partly embedded in the quartz or be scattered through the remaining portion of the pegmatite, which generally is composed largely of feldspar.

"Mica capping" is a miner's term for an aggregation of mica and quartz, with or without feldspar and other minerals, in which the mica is small or occurs in distorted crystals so as to be of small commercial value. The idea conveyed, that the mica forms a capping to a regular "vein" below or near by, is not necessarily true, for some such deposits carry nothing but "mica capping." The mica of "mica capping" commonly occurs in "wedge" shaped blocks with the "A" structure, in many places is more or less distorted or twisted, and may contain inclusions of quartz.

Aggregations consisting wholly or almost wholly of mica crystals occur in some of the pegmatites. Some of these masses measure several feet across. The crystals composing such massive mica range from a small fraction of an inch to 2 inches or more in diameter and thickness. Massive mica generally occurs in irregular-shaped bodies without definite arrangement in the pegmatite.

A large number of minerals have been found associated with mica in pegmatite. Some of these have commercial value in manufacturing industries, or as gems and specimens. The feldspar associated with the mica deposits of North Carolina has not yet been used commercially, but the kaolin formed by its decomposition has been mined extensively. Some of the kaolin deposits are worked for that mineral alone, as they contain little if any merchantable mica. Numerous deposits that may prove of value for both mica and kaolin are known.

DESCRIPTION OF MINES.

MACON COUNTY.

Smith or Baird mine.—The C. D. Smith mine is about a mile west of Franklin. It was worked on a large scale by aborigines, as described below. The mine was opened in the early days by C. D. Smith, and last in 1905 and 1906 by Mr. Eldridge, of Franklin. None of the operators were successful in finding large bodies of mica after the work of C. D. Smith. Some of the later workings cut through layers of scrap mica in old dumps and openings filled with rubbish. Some of this scrap mica was of sufficiently good quality for electrical uses. Several shafts were sunk near the old openings on the top of the ridge but failed to locate the "vein." One of the later tunnels from stream level encountered the filling material of ancient workings and could not be driven farther on account of the loose ground caving badly. About 75 yards northwest of the shafts, across a small branch, a small amount of work was done along a quartz ledge striking N. 60° W. The country rock at this mine is mica gneiss, containing more or less biotite and garnet, with a few diorite inclusions. The mica has a clear "rum" color and is of good quality. Considerable biotite is associated with the muscovite. A large sheet of mica measuring 16 by 18 inches is still kept in the Baird house near the mine as a specimen of the material obtained during the operations of C. D. Smith. The early operations at this mine have been well described by Mr. Smith [a] and his description is quoted below:

The ancient works on my own farm are the most extensive I have yet seen and are therefore worthy of description. The vein, as I have proved by my drifting upon it, has a general strike of N. 73° W., S. 73° E. So far, however, as I have drifted upon it, it runs in a zigzag along this general strike. The old excavation commences at a small branch and runs at a right angle from it into a ridge that juts down with a gentle slope. The dump material has been thrown right and left for the first hundred feet. I tunneled in diagonally and struck the vein 60 feet from the branch, and have drifted along it 40 feet. Here we reach an immense dump rim, 65 feet higher than the level of the branch, and which seems to have been thrown back upon their works. It forms at this end a circular rim to the continued excavations higher up the ridge. The whole length of the excavation from the branch to the upper end of the cut is about 320 feet. The material removed from the upper part of the cut was carried up the hill as well as down it. The dump on the upper side of this upper part of the cut, and at the widest point, is about 25 feet above the bottom of the excavation, and at this point dump and excavation measure about 150 feet across. At the upper end of my tunnel the old digging has been carried down about 30 feet below the surface. If the excavation at the point just mentioned was carried as deep as the work at the upper end of the tunnel, it would make the dump heap on the upper side 55 feet higher than the bottom of the old works. I have been thus particular, in order to show that with mere stone implements it must have required a series of years and a large force to have accomplished such results.

Iotla Bridge kaolin and mica mine.—The Iotla Bridge mine, 4 miles N. 10° W. of Franklin, has been worked for both kaolin and mica. The last work was by the Franklin Kaolin and Mica Company in 1907. The deposit lies in the hill along the west bank of Little Tennessee River, near the mouth of Iotla Creek. The developments consist of eight or ten tunnels, about the same number of shafts and pits, and two good-sized open cuts. The deepest shaft is 65 feet deep and was sunk from the summit of the hill, 120 feet higher than the lowest opening. Two other shafts were sunk to depths of 40 and 45 feet and connected with underground works. The workings extend over a distance of 550 feet, starting in a northwesterly direction at the south end, swinging to north and south along the hilltop, and ending with a northeasterly trend at the north end. The kaolin formation and country rock have the same sweeping curved trend. The country rock is mica gneiss with associated hornblende gneiss streaks.

The pegmatite is irregularly conformable with the inclosing gneiss and may not be one body over the whole length of the developments. The thickness of the pegmatite body varies from a few feet to nearly 100 feet. In places the feldspar component is massive and has

[a] Smith, C. D., Ancient mica mine in North Carolina: Rept. Smithsonian Inst., 1876, pp. 441-443.

thoroughly decomposed, giving large masses of pure kaolin. In other places there is considerable mica and quartz mixed through the feldspar, and these still remain in the kaolin. Large bodies of sugar quartz were encountered in the workings and a large mass outcrops on the hilltop west of the shafts. Bowlders of quartz are scattered over the hillside below part of the pegmatite outcrop and in the river along the west bank at the north end of the deposit. The greater part of the mica yield from this mine has been in small sizes. During 1907, however, one large crystal that weighed over 4,000 pounds was found in a small tunnel connecting with the 65-foot shaft. This crystal was somewhat irregular in shape, though possessing a rough rhombic outline. It measured about 29 by 36 inches and was about 4 feet thick. It was not sufficiently solid to yield sheets of this size, though much material 12 to 18 inches square was obtained. The block was sold in the rough for $1,500. The quality of the mica from this mine is excellent and the color a rich "rum."

Chalk Hill mine.—The Chalk Hill mine is 1½ miles east of Burningtown. Operations have extended over a distance of 200 yards up the west side of a ridge to the top and for 150 yards down the east side. The principal workings with the deepest shafts are on the west side of the ridge considerably below the top. The country rock is interbedded hornblende and mica gneiss, with a strike of N. 80° E. and dip of 75° N. The main lead of the mica deposits is parallel with the schistosity of the country rock, though small streaks of pegmatite were observed cutting the strike of the gneiss. Outcrops of massive sugary quartz occur along the whole line of openings, and large bodies of it were cut in some of the workings. Two or more "veins" have been developed by the main lead of workings. Thirty yards south of the point where the main lead crossed the ridge another pegmatite streak carrying mica was exposed in a cut. The mica from this mine is clear and has a beautiful "rum" color. A little biotite is associated with it, and in some places the two are intergrown

Burningtown or Poll Miller mine.—The Burningtown mine, 3 miles S. 55° E. of Burningtown Bald, was opened before 1880. It was worked intermittently until 1903, and from then until early in 1906 on a larger scale by the Flint Mica Company, of Flint, Mich. This company equipped the mine with electric-power drills, hoisting machinery, and lights. The power drills were discarded during the last year of operation and hand drills only employed. Electricity was generated by a dynamo and turbine using the fall of a neighboring stream. The workings consist of a large open cut, a crosscut tunnel with drifts and stopes, and a small prospect tunnel with short drifts on the level of the open cut. The drifts from the main crosscut tunnel are about 45 feet lower than the open cut. The "vein" has been removed above the drift by a large stope extending to the bottom of the open cut. An incline stope was also driven from the drift to a depth of 45 feet. A plan of the workings is shown in figure 52. A hoist was located in the drift at the end of the crosscut tunnel.

The country rock is mica gneiss with a strike of N. 70° W. to east and west and a dip of 80° N. The pegmatite cuts across the country rock with a strike of N. 10° E. and a dip of 55° E. It varies from 6 to 12 feet in thickness and carries quartz streaks. One of these has a maximum thickness of 4 feet and is near the middle of the pegmatite. The mica yield is from the feldspar streaks between the quartz and mica gneiss walls. The quality of the mica from the Burningtown mine is excellent and the color a clear "rum." The production is said to have been large while the mine was in operation.

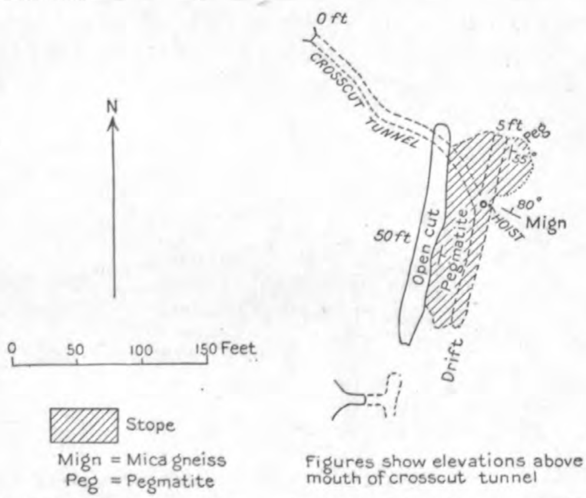


FIGURE 52.—Plan of Burningtown or Poll Miller mine, Macon County, N. C.

Hall and Welch mines.—The Hall and Welch mines are on opposite sides of the same ridge, 5 miles N. 60° W. of Franklin, and may well be described together. The relative position of the two mines, with a plan of the workings and details of the geology, is shown in figure 53. At the Hall mine the tunnels on the northeast were started nearly at stream level and were carried in as crosscuts and drifts on the "veins" to the bottom of a shaft 80 feet deep. From a higher level in this shaft a crosscut leads to extensive workings on the north. These workings and the shaft have partly fallen in. Farther up hill a line of pits and shafts shows the position of another "vein." Still farther south along the summit of the ridge is another line of outcrop workings with a shaft 40 feet deep at the east end. Openings have been made for a distance of nearly 250 yards along this lead and assume a southwesterly course farther west along the ridge. More than 120 yards to the south and 115 feet lower down the hill a new crosscut tunnel has been driven in, cutting the "vein" that forms the crest of the ridge and another "vein" about 60 feet south of it. The latter "vein" is 2 to 8 feet thick and has also been prospected along the outcrop. Drifts have been run both east and west along this pegmatite, and a 50-foot raise with stope has been made on the east side of the crosscut tunnel. The pegmatite forming the crest of the ridge is about 14 feet thick where cut by the tunnel. Two quartz streaks from 1 to 3 feet thick are inclosed in the pegmatite parallel with its direction. This pegmatite body cuts across the mica gneiss country rock in part, with a varying east-west strike and nearly vertical dip. The mica yield has come chiefly from the two outside feldspar streaks between quartz and mica gneiss walls,

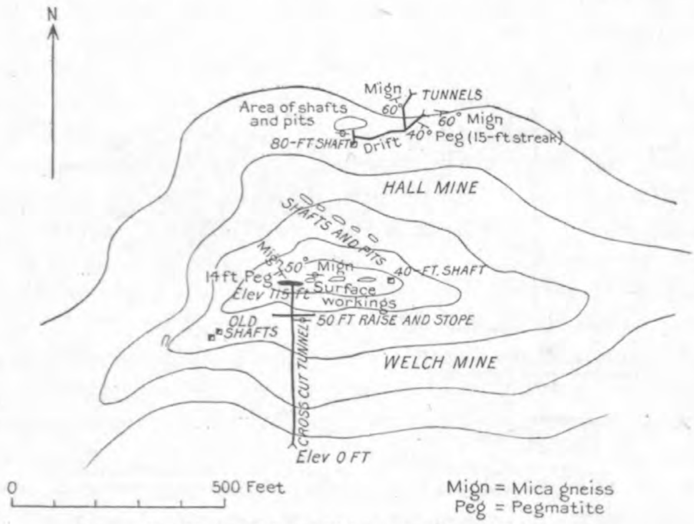


FIGURE 53.—Plan of Hall and Welch mines, Macon County, N. C.

but a small amount has been obtained between the two quartz streaks. The mica obtained from these mines is of fine quality, with a clear "rum" color.

Neal Bryson mine.—The Neal Bryson mine is 1 mile south of West Mills, on the east side of Little Tennessee River. The mine is in a small depression in a steep hillside. In this depression the soil has accumulated to a depth of several feet and carries mica from the breaking down of former pegmatite bodies. A small amount of "groundhog" mining has been done in this soil and débris for its mica content. The principal workings consist of an old shaft with drifts and stopes on the vein, a new 180-foot crosscut tunnel, and a shaft with other drifts. The mouths of the shafts are about 60 feet above that of the crosscut tunnel. The old stopes from the old shaft extend down to the level of the new tunnel. The drift from this tunnel to the east connects with the new shaft on this level and on a small level 15 feet above. The position of the workings, with details of the formation, is shown in figure 54.

The pegmatite has an irregular east-west strike, with a varying dip that shows considerable warping. The dip ranges from vertical to 70° N. in one place and to 30° S. at the west end of the workings. The "vein" varies from 1 foot in thickness in one part of the workings to 12 feet in others. A quartz streak varying in thickness with the thickness of the pegmatite is included near the middle of the pegmatite where the latter is over 3 feet thick. The mica occurs in the feldspar between this quartz streak and the mica gneiss walls. At the east end of the tunnel the "vein" is richest next to the south wall. The quality of the mica from this mine is excellent.

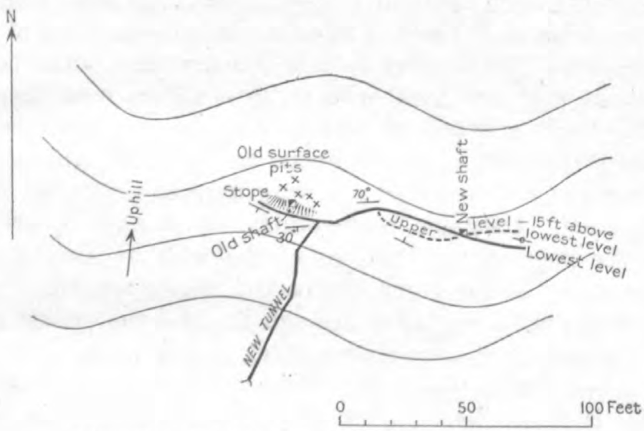


FIGURE 54.—Plan of Neal Bryson mine, Macon County, N. C.

Campbell or Higdon mine.—The Campbell mine is about 1½ miles N. 75° W. of Cowee Gap, where the Webster-Franklin road crosses. Over a dozen tunnels have been run in on probably two or more "veins." The mine is in a shallow cove or hollow on a steep mountain side. The soil accumulation in places in this cove is deep, especially over the lower part of the mine. This soil contains more or less sheet-mica débris from the disintegration of pegmatite veins. Mining through this soil is difficult, as landslides occur. One recent slip has taken place in the cove in which a large body of the soil has dropped down about 10 feet. This slip is evident on the surface above the workings. At the time of visit (1906) there were two tunnels open in hard-rock formation, an old one in slide material was being cleaned out, and another 250 feet long at the base of the old workings was being driven in search of "vein" matter. This tunnel was very crooked, because it was necessary to avoid loose slide rock in several places. In one of the hard-rock tunnels a good pegmatite "vein," about 10 feet thick, was encountered. It contained a 2 to 5 foot quartz streak within its mass. The yield of mica was from the partly kaolinized feldspar streaks between the quartz ledge and mica gneiss walls. The mine has yielded a quantity of fine quality of mica with a clear "rum" color.

Beasley mine No. 1.—The Beasley mine No. 1, also called "Bradley Butt," is one-half mile east of Mica City. It has been operated by a large open cut with a little stoping from its bottom and several tunnels at lower levels on the hillside. Some of these openings are on different "veins" from or branches of the main pegmatite worked in the open cut. The open cut is about 200 feet long and has a maximum depth of 30 feet. One of the tunnels below the cut was run in about 75 yards. The pegmatite was as much as 30 feet thick in one part of the open cut and pinched down into two small streaks 1 and 2 feet wide with 4 feet of mica gneiss between them at the east end of the cut. The country rock is biotite gneiss. The pegmatite strikes about east and west, with a dip of 85° S. near the outcrop and of 30° S. at a depth of 25 feet. The pegmatite cuts sharply across the gneiss and horses of gneiss are included within it. The rock formations are unaltered and very hard at this mine, requiring much blasting. Irregular segregations of massive quartz occur through the pegmatite. Portions of the feldspar have a greenish cast, caused by stains from the partial decomposition of a small amount of sulphides scattered through it. A large pocket of mica, yielding a quantity of large sheets of high-grade mica, is reported to have been found in the open cut. Much of the mica from the Beasley No. 1 mine is of excellent quality, with a clear "rum" color, but some of greenish color with an "A" structure was found in one of the lower openings.

Beasley mine No. 2.—The Beasley mine No. 2 is about one-half mile south of Beasley mine No. 1, on the south side of a high ridge. The deposit has been opened by prospect pits for about 150 yards along the outcrop and by a tunnel with drifts, large stopes, and an incline shaft connecting with the stopes. The lowest tunnel entering the drifts to the stopes is about 75 feet lower than the mouth of the incline entering the stopes on the hillside above. The drift from the end of the tunnel is about 150 feet long and the farther half of it opens up into the stope above. The country rock is mica gneiss, which has an east-west strike and a dip of 65° S. at the mouth of the tunnel. The pegmatite strikes about N. 70° W., with a dip of 40° SW. The pegmatite is more than 15 feet thick in places, but the entire thickness was not removed in mining. The mica evidently occurred more plentifully within the mass than along the walls. In 1906 these old works were being cleared out preparatory to developing new ground. The mica from this mine is of fine quality. A small amount of biotite is associated with it.

Winecoff mine.—The Winecoff or old Jacobs mine is 2½ miles northwest of Franklin. It has been opened for a distance of about 300 yards, in a northwest-southeast direction, by numerous shafts, pits, cuts, and tunnels. A plan of the workings is given in figure 55. At 1 remains of ancient workings were found, and later four shafts with "groundhog" tunnels were made. The pegmatite has a width of about 25 feet where exposed in these openings and is badly decomposed. The principal developments to the northwest were made by the last owner, Mr. Winecoff, before 1907. At 2 a pegmatite ledge was exposed in an open cut varying in thickness from 5 feet at the surface to 8 feet in the bottom of the cut. At 3 a shaft 35 feet deep encountered a pegmatite ledge inclosing quartz bands. At 4 and 5 two shafts reported to be 65 feet deep exposed a pegmatite ledge

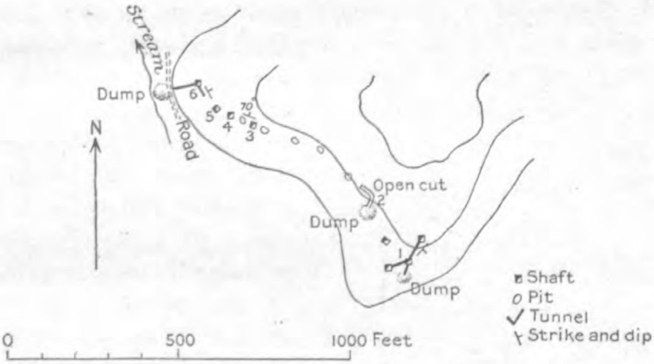


FIGURE 55.—Plan of Winecoff mine, Macon County, N. C.

varying from 2 to 8 feet in thickness and containing quartz bands. At 6 a shaft about 40 feet deep connecting with a crosscut tunnel and drifts encountered a pegmatite composed of a 6-foot streak of quartz with small feldspar streaks along the sides.

The workings at 1 are probably on a different pegmatite body from those to the northwest, though it is possible that a swing in the strike (northwest) at 1 might bring the same pegmatite ledge to 2 and other points. The strike and dip of the pegmatite are shown by appropriate marks at 1, 3, and 6. The banded appearance of the "vein" is marked in openings 3 to 6 by streaks of quartz and mica schist, in the pegmatite and parallel with its walls. The principal yield of mica has been from the workings at 1 and 4 to 6. Possibly the same pegmatite was opened at the old Harris or Raby mine, about 75 yards northwest of and across a branch from the Winecoff mine. The mica from each of these mines has a clear "rum" color and is of fine quality.

JACKSON COUNTY.

John Long mine No. 1.—The John Long mine No. 1 is one-fourth of a mile northeast of the mouth of Wayehutta Creek, 4 miles southeast of Webster. It has been worked by a tunnel 90 feet long and nearly on the strike. At this distance the tunnel forks into two branches, which come together again about 45 feet farther on. Where the tunnels join, an incline working was sunk under the large pillar left between them. There has been some open-cut work on the outcrop—a shaft which passed to one side of the underground workings and an old tunnel now caved in. The position of the workings is shown in figure 56. The pegmatite formation has decomposed badly and is so soft that the tunnels require careful timbering. The greater part of the ground left between the branching tunnels is pegmatite, with the exception of a horse of mica gneiss several feet thick. The pegmatite contains quartz streaks or ledges lying parallel with its general course. Several large blocks of mica and many small ones were seen in the kaolinized feldspar. This mica was more or less fractured and contained a considerable quantity of clay stains between the laminæ. The mica has a clear "rum" color where the crystals have not been clay stained.

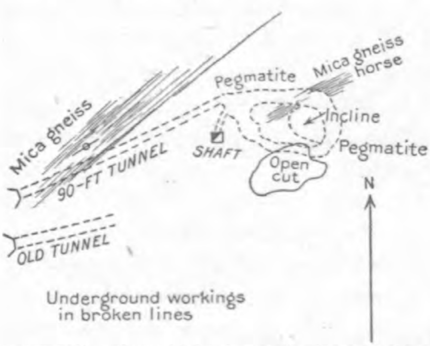


FIGURE 56.—Plan of John Long mine No. 1, Jackson County, N. C.

John Long mine No. 2.—The John Long mine No. 2 is at the mouth of Wayehutta Creek. The mine has been opened by a crosscut tunnel 60 feet long, driven from a point slightly above the creek level, with a 40-foot drift on the "vein." The latter has been stoped out to the surface for a distance of 20 feet and has been removed to a depth of 10 feet below the level of the tunnel. The country rock is biotite gneiss striking about N. 25° E., with a nearly vertical dip. The pegmatite is 10 to 12 feet thick and includes a number of streaks of gneiss. The mica occurs more plentifully along the east wall of the pegmatite and this portion is removed in mining to a width of 5 to 8 feet. The streaks of included gneiss split the pegmatite into lenses and bands from a few inches to a foot or two thick. The formation is fresh and hard from the surface down and requires much blasting. The mica is of fine clear "rum" color. It is reported that during three months of 1906 $400 worth of rough mica was obtained.

Painter mine.—The Painter mine is 2½ miles S. 65° E. of Sylva, in the northwest slope of a small mountain. The mine was opened many years ago by two shafts, with drifts, and a tunnel at a lower level but not connecting with the shafts. Later, more systematic operations resulted in a tunnel 175 feet long opening into a stope nearly 200 feet long. The stope was carried to a depth of 40 feet below the tunnel level and some 20 feet above, being very irregular in shape. A longitudinal section through the "vein" showing the shape of the workings is given in figure 57. The country rock is garnetiferous mica gneiss which has a strike of N. 35° W. and a high dip to the southwest. The pegmatite is approximately conformable with the inclosing gneiss. The "vein" varies from 2 to more than 15 feet in thickness at the end of the stope. A large quartz streak in the middle of the pegmatite in this stope is left as a foot wall for the workings. The mica streak lies between this and the hanging wall. It is possible that more mica might be found by further prospecting the feldspar streak between the quartz streak and the foot wall. Several large blocks of mica were exposed in the face of the stope at the time of examination (1905). The mica is mostly clear and of good quality,

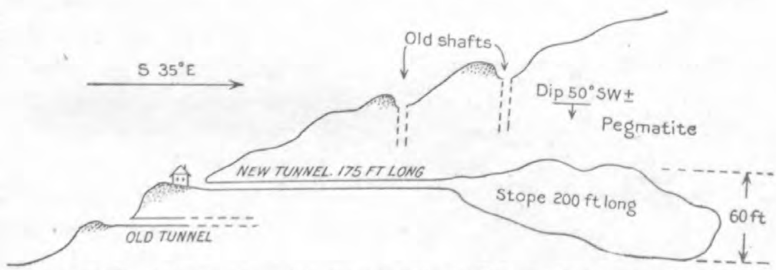


FIGURE 57.—Section in plane of the "vein" at the Painter mine, Jackson County, N. C.

though a small amount of "specked" material was seen on the dumps. A strip of "ruled" mica of fine clear "rum" color saved as a specimen at the mine measured 2 by 15 inches. It exhibited the "A" structure slightly at each end, but was perfectly sound in the middle.

The mine is equipped with a hoisting engine and pump at the mouth of the tunnel and a track in the tunnel and stope.

Piney Mountain mine.—The Piney Mountain mine is 1 mile north of Sugarloaf Mountain, in the summit of a small knob. The mine has been worked by open cuts, crosscut tunnels, drifts, stopes, and shafts. The positions of these workings are shown in plan view in figure 58. Evidently work has been done on three separate "veins" with varying, nearly northerly strike and approximately vertical dips. The westerly "vein" was followed from the open cut by a drift with a stope to the surface and a shaft in the bottom of the open stope. At the end of the drift the pegmatite was only 2 feet thick, but it was still fairly rich in mica. An open cut with a shaft in the bottom was made on the middle vein and a stope driven southward from the cut. A crosscut tunnel was also run to the drift on the west "vein" for the easy removal of waste. The easterly "vein" was the first opened and the workings on it have fallen in badly. It is reported that the mica-bearing part was stoped out.

The country rock is mica gneiss. It is cut by small masses and streaks of pegmatite in various directions. The pegmatite worked for mica ranges from 1 to 12 feet in thickness. A quartz streak is generally present in the interior of the pegmatite and oriented parallel with its walls. This mine is reported to have been a good producer of mica.

Big Flint mine.—The Big Flint mine is about half a mile west of south of Wesner Bald and about 200 feet above one of the forks of Cabin Creek. The mine takes its name from the immense bowlder-like mass of white quartz that marks its outcrop. Several "groundhog" pits and tunnels have been made under the quartz mass, to the west of it, and on the hillside below it. Large masses of quartz outcrop in the branch about 100 yards east of the mine. The country rock is mica gneiss with an east-west strike and a dip to the south. The "Big Flint" mass of quartz is about 40 feet across and at least 25 feet thick. It does not appear to have any connecting mass below, for excavations have been made under a large portion of it from each side and have encountered only kaolin and mica. The under side of this quartz mass is rounded and is composed of overlapping lenticular and shell-like masses of quartz from an inch or two to a foot thick. Fine partings of mica have developed in the seams between these lenses. The feldspar, entirely altered to kaolin, is massive under the quartz mass. This kaolin also shows lens-shaped layers with parting seams or slips about parallel with those in the quartz. In the openings west of the quartz mass the feldspar formation is massive and contains streaks rich in small mica crystals. A wall of mica gneiss exposed here, probably a horse, has a north-south strike and dips 45° E. The mica obtained from this mine is principally in small sizes, but is of light color and good quality.

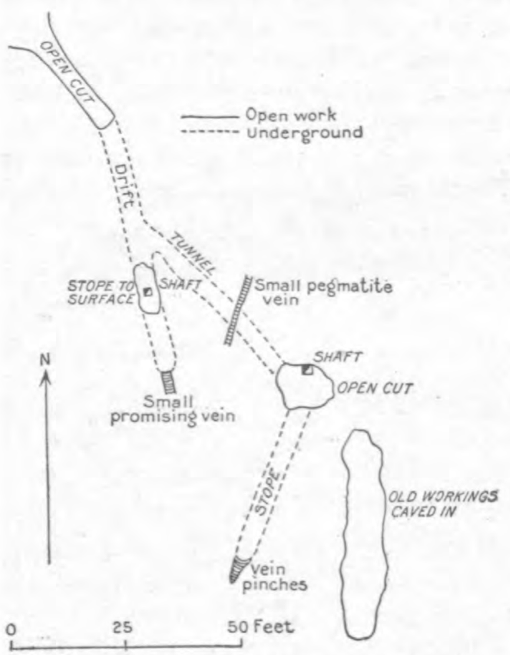


FIGURE 58.—Plan of Piney Mountain mine, Jackson County, N. C.

Wayehutta kaolin and mica mine.—The Wayehutta kaolin and mica mine is on the west side of Black Mountain, near the head of Wayehutta Creek and 3 miles due south of Willetts. The mine is 300 or 400 feet above the valley, on the side of a steep ridge, near and on the top. Developments consist of an 80-foot tunnel with 45 feet of crosscutting and two interior shafts on the pegmatite, with several other trial tunnels and openings. The latter do not expose the main body of the pegmatite. Figure 59 shows the position of the different openings and the formations encountered in each. The country rock is mica gneiss with a strike of N. 60° to 70° E. and a southeasterly to vertical dip. The pegmatite contains in places streaks or horses of mica gneiss, and its contact with the gneiss is highly irregular. A massive quartz vein 2 feet thick was encountered near the southeast side of the pegmatite. Another quartz ledge, 3 feet thick, outcrops on the top and opposite side of the ridge, 40 yards southeast of the kaolin deposit. Workings on this quartz ledge show that it is not directly connected with the main body of the pegmatite. The feldspar of the pegmatite is thoroughly decomposed and in places has altered to large masses of pure kaolin. The upper 12 feet of the 30-foot interior shaft and 9 feet of the 10-foot shaft were cut through kaolin. A small amount of clear "rum" colored mica was found in parts of the workings.

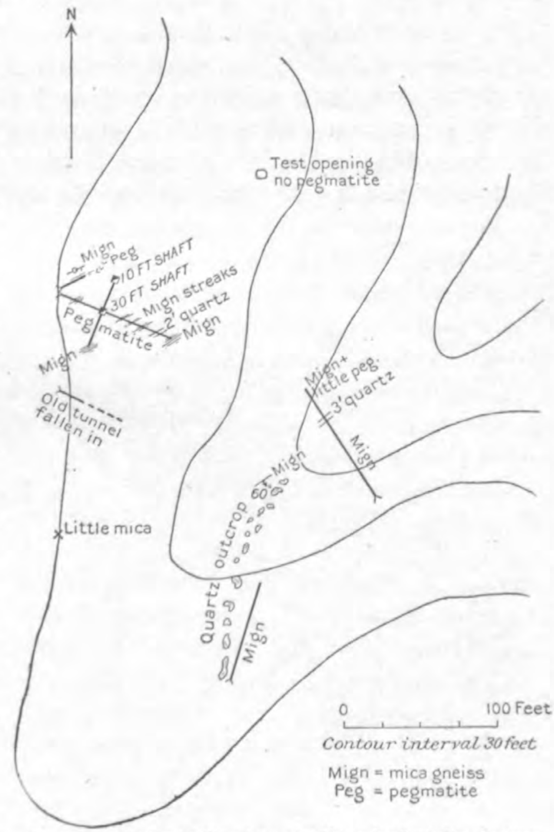


FIGURE 59.—Plan of Wayehutta kaolin and mica mine, Jackson County, N. C.

Cedar Cliff mine.—The Cedar Cliff mine is one-fourth of a mile east of the Deep Gap of Black Mountain. The mine is located in the face of a cliff of hard rock. It has been operated by an open cut nearly 60 feet high and 5 to 25 feet back in the face of the cliff. The country rock is garnetiferous mica gneiss, striking N. 45° E. with a northwest dip. The pegmatite cuts across the gneiss with a strike of N. 10° E. and nearly vertical dip. The "vein" varies from 1 to 3 feet in thickness and contains streaks of quartz parallel with its walls. Other pegmatites outcrop in the cliff and some show indications of mica in commercial sizes. The mica is clear and of good quality.

Leon Hooper mine.—The Hooper mine is on the road along Moses Creek, a little more than a mile above its mouth. It was worked by an open cut 60 feet long and 10 to 18 feet deep along the "vein" close to the roadside, and a crosscut tunnel under the road to remove waste. The country rock is mica gneiss, which strikes N. 50° E. with a dip of 75° SE. The pegmatite is conformable with the inclosing gneiss and has a thickness ranging from 5 to 12 feet. In the thicker portions the whole of the pegmatite was not removed, only that containing a "lead" of pockets in the interior being mined. The mica gneiss is very schistose near the contact with the pegmatite. The latter contains a few sheets of quartz lying parallel with its walls. One of these quartz streaks near the northeast end of the cut was 18 inches thick, pinching out in a distance of a few feet. The mica at this mine has a dark-brown color in sheets one-sixteenth of an inch or more thick, but is clear when split into thin sheets. Part of it is a little "specked."

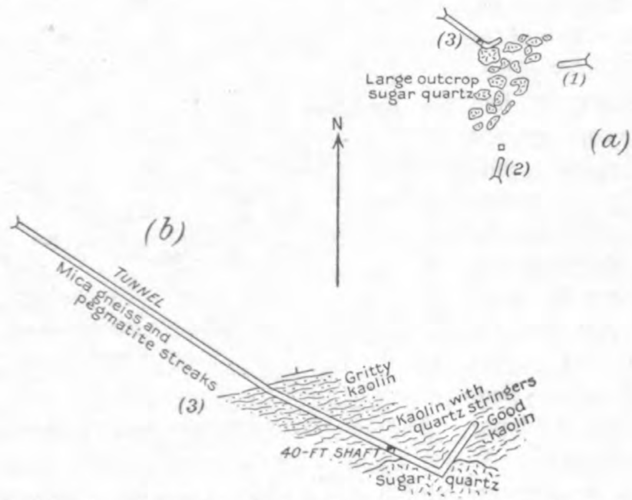


FIGURE 60.—Roda kaolin and mica mine, Jackson County, N. C. (*a*) Plan; (*b*) details of tunnel 3, shown in (*a*).

Roda kaolin and mica mine.—The Roda mine is on the south side of Tuckasegee River opposite the mouth of Caney Fork. The deposit lies in the summit of a low rounded hill and has been proved on three sides by tunnels and pits. The relative position of these workings is shown in figure 60 (*a*). The deposit has a large outcrop of massive, coarse, sugary quartz over it, and this quartz was also encountered in the workings. The first work was for mica on the south side of the hill and in this the large mass of kaolin was exposed. The principal development is a crosscut tunnel on the west side. This cuts masses of both gritty and very good kaolin and sugar quartz. A 40-foot shaft was sunk from the interior of this tunnel and encountered kaolin through its whole depth. A diagram of this tunnel is shown in figure 60(*b*). The tunnel on the east side of the deposit was driven 18 feet in a mass of fairly pure kaolin after passing through a number of feet of soil.

Pinhook Gap mine.—The Pinhook Gap mine is on the southwest side of the gap of that name in Tennessee Ridge. This mine has been worked extensively at various times. During 1905 a new deposit was opened about 250 yards southwest of the old workings. C. H. Wolford operated the Pinhook Gap mine during part of 1905 and 1906. He reported a production of about 600 pounds a week of merchantable sheet mica during part of this time.

The older workings consist of a large open cut with a crosscut tunnel driven from its southwest corner a short distance out into the pegmatite, and thence turning along the strike of that rock. This connects with a tunnel driven in from the southwest at a lower level. Other short tunnels were driven from the open cut in various directions. Numerous pits and crosscut trenches were made a short distance to the northeast. The pegmatite is irregular in shape, swelling from a thickness of a few feet to the southwest to 30 feet in the open cut and nearly 50 feet northeast of it. Quartz segregations and streaks are scattered through it. On the east side of the open cut a mass or boss of garnet-mica rock or "mica capping" several feet across was encountered. It was composed of bunches of "wedge" shaped mica crystals showing the "A" structure, with coarse garnets scattered thickly through it. The mica crystals ranged from a fraction of an inch to 3 inches across and the garnets from small size to nearly 2 inches in diameter. The garnets constitute at least 25 per cent of the whole mass and are found to be fresh and firm on crushing, even if apparently badly weathered on the surface.

Operations at the later workings consist of a shaft 30 feet deep with a drift on the vein and a crosscut tunnel from the hillside below. The country rock is mica gneiss, which strikes N. 40° E. with a dip of 40° NW. The pegmatite is conformable or nearly so with the strike of the gneiss. The outcrop of the "vein" is marked by large masses of quartz. These quartz masses are irregular in shape and some of them pinch out at small depth. The feldspar part of the pegmatite is also irregular in shape. It is 6 feet thick at the surface in the shaft.

The mica from the Pinhook Gap mine has a brownish color and is partly "specked." Large-sized sheets are sometimes obtained, however, in which the "specks" can be eliminated by splitting.

Jim Wood mine.—The Jim Wood mine is on the west side of Wolf Creek, about a quarter of a mile above the Wolf Mountain road. It was worked by an open cut about 50 feet long and an open incline stope 20 feet deeper from its bottom. The country rock is mica gneiss with a layer of gritty talc schist a few feet southeast of the peg-

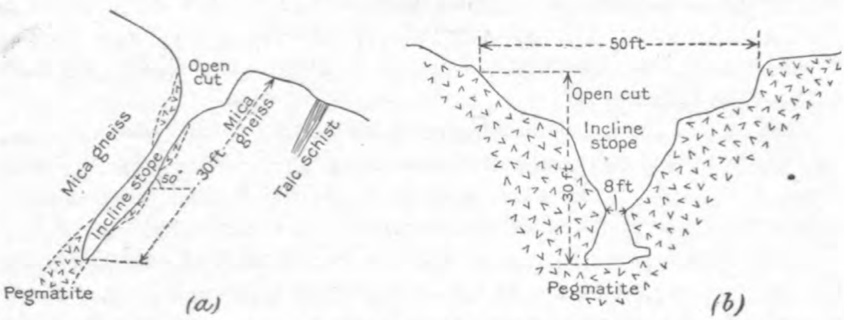


FIGURE 61.—Jim Wood mine, Jackson County, N. C. (*a*) Cross section; (*b*) section in plane of the "vein."

matite. The latter is conformable with the inclosing gneiss and strikes N. 70° E. with a dip of 50° N. The "vein" was rich in mica near the surface for the whole length opened, but was sufficiently rich to work for a length of 8 feet only near the bottom of the incline. At the bottom of the incline the "pay streak" became longer again. The whole thickness of the pegmatite was not removed, only that portion carrying the mica streak being mined. The workings and geologic relations are shown in cross and longitudinal sections in figure 61, (*a*) and (*b*). The mica has a dark-brown color in sheets of sufficient thickness, and part is "specked." Some of the crystals are well developed and others are partly "wedge" shaped.

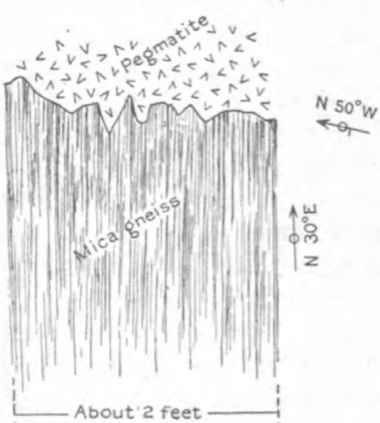


FIGURE 62.—Uneven contact of pegmatite and mica gneiss at the Gregory mine, Jackson County, N. C.

Gregory mine.—The Gregory mine is 1 mile S. 20° W. of Panther Knob, near the top of the ridge running south from that mountain to the Cullowhee Mountain divide. It was worked by an open cut about 50 feet back into the mountain side. On one side of the cut a deeper cut and room had been stoped out. The deepest part was probably not over 25 feet deep. The country rock is mica gneiss, which strikes N. 30° E. with a vertical dip. The pegmatite cuts across the gneiss with a strike of about N. 50° W. and a vertical or high southerly dip. It is at least 10 feet thick in places and contained large quartz streaks and masses, one 4 feet through.

The contact with the mica gneiss is not sharp, and in one exposure along the southwest wall was jagged, as shown in figure 62. Small mica is plentiful in parts of the "vein" and some good-sized crystals were left in a pillar over the stope. The mica has a "rum" color and is of good quality.

Bowers mine.—The Bowers mine is 1 mile S. 30° E. of Panther Knob. The mine is in the east face of a steep mountain side, almost a cliff. It was worked by an open cut, not as wide as the pegmatite, 40 feet long into the mountain side, and with a maximum depth of 35 feet. A shaft was sunk from the inner end of this cut. The country rock is hard mica gneiss which strikes N. 55° E. and dips 70° NW. The pegmatite carries a large amount of quartz and is very hard. Near the top of the cut the pegmatite forks, a small streak, worked out for several feet, running westward and the other streak running northwestward. The mica is of excellent quality and has a fine "rum" color.

Judge Ferguson mine.—The Judge Ferguson mine is about $5\frac{3}{4}$ miles S. 55° W. of Webster. It is one of the older mines and was reopened in 1906 by Mark Bryson. The workings at the time of visit consisted of an old open cut, two old shafts from the surface, and an interior shaft 55 feet deep at the end of the crosscut tunnel, with drifts and stopes. The new work consisted of a tunnel 180 feet long run irregularly toward the old workings and at a level 65 feet lower than the old tunnel. A plan of these workings is given in figure 63. The new tunnel had to be driven a distance of about 25 feet to cut the pegmatite, which it is reported subsequently to have done.

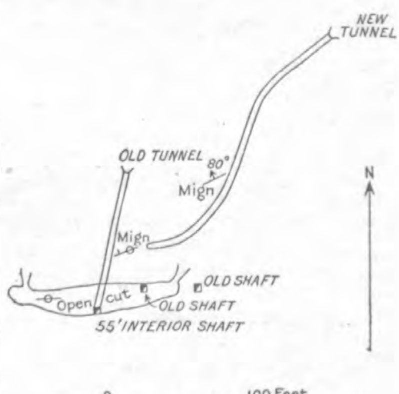


FIGURE 63.—Plan of Judge Ferguson mine, Jackson County, N. C. Mign, Mica gneiss.

The pegmatite strikes about east and west, with a vertical dip cutting across the mica gneiss country rock at a small angle. The latter has a strike slightly north of east and an approximately vertical dip. The pegmatite is about 12 feet thick in the old workings and contains a large quartz streak through part of its course. The mica occurs in the feldspar streaks between the quartz and wall rocks. It has a clear light color and much of it is of good quality, though a portion has the "A" structure.

J. H. Rochester mine.—The Rochester mine is one-third mile southeast of Ocala post-office. It comprises two workings on different pegmatite bodies. In the one to the northwest an incline had been run down on the "vein." The country and wall rock at each opening is pegmatized mica gneiss striking N. 30° E. and dipping 50° SE. The pegmatite is conformable with the inclosing gneiss and about 3½ feet thick. About four-fifths of it, as exposed, consists of quartz. The mica is more plentiful near the walls of the pegmatite.

The principal work was done 75 yards to the southeast and consisted of an open cut 10 to 20 feet deep and 50 feet long on the outcrop, with a crosscut tunnel and drifts, about 100 feet in all, at a lower level and under the open cut, as shown in figure 64. The pegmatite is from 1 to 5 feet thick and is conformable with the inclosing gneiss. Massive quartz is more or less prominent in different parts of the pegmatite. The mica is clear and has a dark-brown color with a tinge of green.

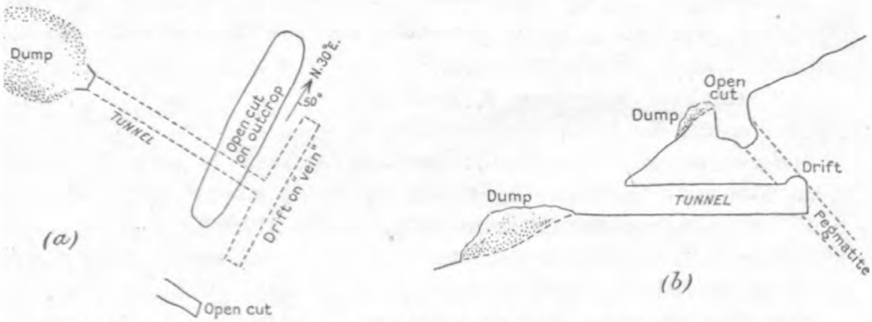


FIGURE 64.—J. H. Rochester mine, Jackson County, N. C. (*a*) Plan view; (*b*) cross section.

TRANSYLVANIA COUNTY.

Bee Tree Fork mine.—The Bee Tree Fork mine is on the hillside opposite the mouth of Bee Tree Fork, on the headwaters of French Broad River. It was opened some years ago by Tarry McCall, and after lying idle many years was reopened in 1905 by C. H. Wolford. It has been operated by an open cut 50 feet long and 35 feet deep at the deeper end in the hillside. The cut is but little wider than the thickness of the "vein." The country rock is mica gneiss, which strikes about northeast with a dip of 45° NW. The "vein" has an irregular easterly strike with a dip varying from 45° to 80° N., cutting across the country rock with a sinuous course. The pegmatite ranges from 2 to 8 feet in thickness and is composed largely of quartz with smaller amounts of feldspar and mica. A small amount of pyrite and pyrrhotite is scattered through the rock. The mica has a clear "rum" color and is of good quality.

Reed mine.—The Reed mine is 1 mile N. 60° E. of Montvale and 2¼ miles S. 20° E. of Sapphire. It is owned by Dr. Robert Grimshawe, of Montvale. The mine has been worked by several tunnels at different levels, the greater part of which have fallen in. One 30-foot tunnel was driven in on a 5-foot "vein," which had a north-south strike and a dip of 30° W. This pegmatite is irregularly conformable with the inclosing mica gneiss country rock. It has a 2½-foot quartz streak in the middle with mostly feldspar on each side. About 75 feet to the north, on the opposite side of a small valley, the same "vein" has been worked by two levels (now stoped out between). One of these levels was driven back about 100 feet. The pegmatite had a strike of about N. 20° E. and a dip of 35° NW. in this tunnel. It had pinched down to about 18 inches in thickness with small scattering quartz lenses in it at the end of the tunnel. The mica from the Reed mine has a dark color and in part is "specked" with magnetite.

HAYWOOD COUNTY.

Shiny mine.—The Shiny mine is near the head of Allen Creek, 1¼ miles north of Richland Balsam Mountain. It is 450 feet above the creek in the steep, cliff-like face of the west valley wall. Access was obtained over a rough trail and several sets of ladders. The workings consist of an open cut nearly 200 feet long in a north-south direction along the side of the mountain and up to 25 feet deep. The country rock is very hard garnet gneiss, which has a northerly strike with nearly vertical dip. The pegmatite is conformable with this and pinches and swells from a few inches to several feet in thickness, with streaks branching out from it. The pegmatite contains quartz masses and streaks. Pyrrhotite is scattered through both the country rock and part of the pegmatite. The mica is rather thick in parts of the "vein," though only small-sized crystals were left exposed from the last operations. Sheets measuring 5 and 6 inches across were seen at the old trimming house in the valley below the mine. The quality of these sheets was very good.

BUNCOMBE COUNTY.

New Balsam Gap mine.—The New Balsam Gap mine is near the head of North Fork of Swannanoa River, about 1 mile southeast of Balsam Gap. The mine is on the face of a cliff about 70 feet high and a few feet to one side of a waterfall over the cliff. It was worked by an open cut at the foot of the cliff, about 60 feet long, extending into the cliff. A tunnel or stope 15 or 20 feet high was then driven back under the cliff on the "vein" a distance of 70 feet. The full width of the pegmatite, 6 to 8 feet, was removed in the tunnel, and the waste was left to accumulate in the bottom as a floor for stoping out the "vein" above. The country rock is much-folded biotite mica gneiss striking north and south, with a high irregular dip to the west. The pegmatite cuts across the schistosity of the country rock with a strike of N. 45° E. and a nearly vertical dip. The pegmatite is very irregular in size and in one portion exposed in the roof of the tunnel it pinches down to about 1 foot in width but abruptly elbows out again to several feet, as shown in figure 65 (*a*). The irregularity of the pegmatite is further shown by the exposure in the end of the tunnel, of which figure 65 (*b*) is a vertical cross section. The pegmatite pinches down in the upper part, is large in the middle, and smaller again at the bottom. On the west side there is an elbow in the "vein" with a small arm of pegmatite branching off into the mica gneiss. An irregular-shaped horse of gneiss was included in the "vein." The pegmatite is composed of the usual minerals segregated out into coarse masses in places. The quartz and feldspar occur in masses 2 or 3 feet thick, and the mica is richer in some portions than in others. One place in the roof where the pegmatite pinched down to a width of 2 feet carries abundant mica. The mica is good and has some biotite associated with it.

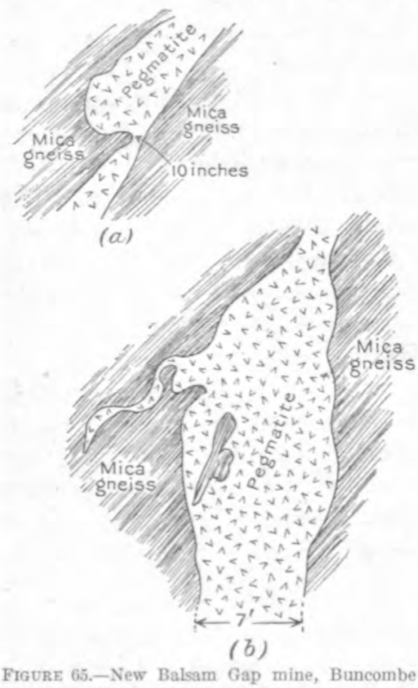


FIGURE 65.—New Balsam Gap mine, Buncombe County, N. C. (*a*) Section showing pegmatite pinched down to 10 inches and elbowing out abruptly; (*b*) irregularity of pegmatite exposed in end of tunnel; lenticular-shaped cross section with small side stringer and horse of mica gneiss.

Connally mine.—The Connally mine is 4 miles west of north of Black Mountain station, on the east side of North Fork of Swannanoa River. The country rock is diorite or hornblende gneiss, carrying mica gneiss bands. The mine was formerly opened by cuts and shafts on the hillside about 100 yards above the entrance to a new tunnel. The outcrop of the pegmatite at the old workings was marked by much massive quartz. A new shaft had been sunk near the old workings and pegmatite was encountered. The new tunnel was driven in a northerly direction for nearly 200 feet. Side tunnels were run near the end, as shown in figure 66, *A*. Irregularities in the formation were encountered at several places. At 1, figure 66, *A*, a small lens or streak of pegmatite cuts across the hornblende gneiss walls of the tunnel. At 2 there is a vertical contact of hornblende gneiss on the left and pegmatite on the right. For a number of yards at 3 there is hornblende gneiss in the bottom of the tunnel and pegmatite in the upper part. At 4 the pegmatite gives out and hornblende gneiss is encountered. The irregular nature of this contact is shown in figure 66, *B*, which represents the section (*a*) exposed on the east wall. The feldspathic part of the pegmatite forks into mica gneiss. At 5 and 8 there are irregular streaks of massive quartz. Between 6 and 7 there is a vertical contact between pegmatite and hornblende gneiss. At (*b*) there is another large irregular mass of quartz included in or a part of the pegmatite. It is shown in cross section in figure 66, *C*, as it appears in the north wall of the tunnel.

The feldspar of the pegmatite is badly kaolinized, and it was the intention of Colonel Connally to test the deposit for kaolin. The mica occurs chiefly in the kaolin along the quartz masses and is much crushed in many places. The quantity of mica found in the new

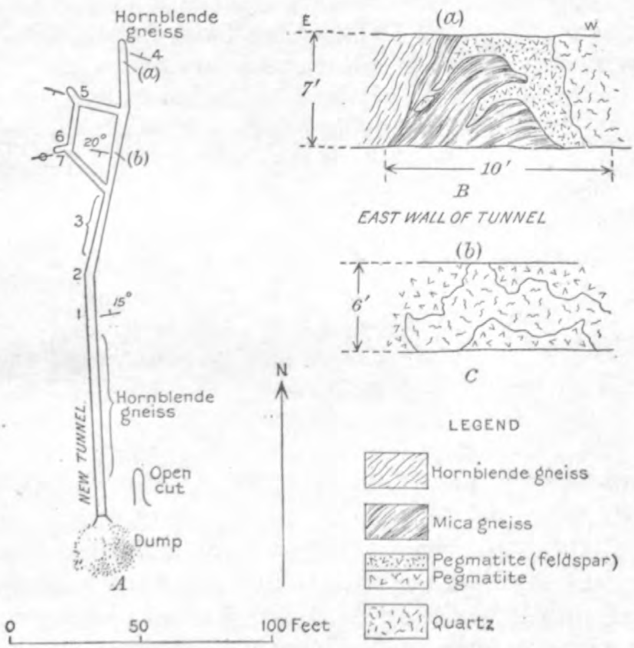


FIGURE 66.—*A*, Plan of Connally mine, Buncombe County, N. C.; reference figures described in text. *B*, Section in east wall of tunnel at (*a*) in *A*. *C*, Section in east wall of tunnel at (*b*) in *A*.

tunnel was not large, but the old workings on the hill above are reported to have yielded well. The mica obtained was of clear light "rum" color and good quality.

YANCEY COUNTY.

Poll Hill mine.—The Poll Hill mine is $1\frac{3}{4}$ miles west of south of Newdale, on the east side of South Toe River, just across the river from the Gibbs mine. This mine consists of two parts, both of which have been operated intermittently and actively since 1906. The part near the bank of the river was worked by the Burleson Mica Company, and that higher up on the hill by Hall Brothers & Burleson. The part near the river was being cleaned out at the time of visit and was equipped with a steam pump and hoist. The workings consist of an incline about 20 feet deep on the pegmatite and a tunnel to the northeast of it. The country rock is mica gneiss which strikes about N. 75° E. and dips 55° S. The pegmatite is only approximately conformable with the gneiss, and so far as seen varies from 10 to 15 feet in thickness. It contains numerous small horses or streaks of mica gneiss or schist included parallel with its walls.

The upper part of the mine has been worked at a number of places, and in such positions as to show an irregular pegmatite formation or several masses of pegmatite. The last operations had been in progress about one year at the time of visit and the nature of the work is shown in figure 67, *A*. A 70-foot tunnel was driven in a N. 75° E. direction on a mica "vein." From this an incline was run in a southwesterly direction on a dip of about 35°. The incline was about 70 feet long, 20 feet wide, and 10 feet high. A bench was left on the

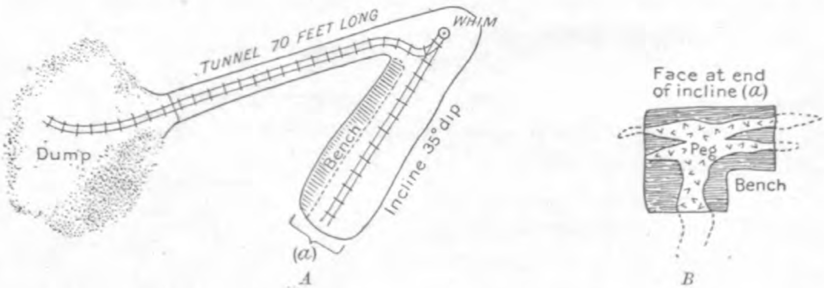


FIGURE 67.—*A*, Plan of Poll Hill mine, Yancey County, N. C. *B*, Cross section of pegmatite at end of incline at (*a*) in *A*.

northwest side in barren rock. The waste and mica were hoisted from the incline by means of a hand whim at the head of the incline.

The wall rock is biotite gneiss, through which the pegmatite cuts and into which it forks out. Figure 67, *B*, represents the vertical cross section of the pegmatite exposed in the face at the bottom of the incline. The position of the bench in barren gneiss is shown on the side. The incline was driven on the pegmatite where that rock was diverted from its course across the gneiss into lens-shaped masses. These lenses became smaller or pinched out in a short distance on each side.

The quality of the mica from the Poll Hill mine is good and the color a clear "rum."

Aley mine.—The Aley mine is at the head of Browns Creek, about 3 miles southwest of Micaville. It has been opened by at least three tunnels, one an incline, and by open cuts and a shaft 40 feet deep. The last work was that of the J. E. Burleson Company in 1904. The "vein" strikes N. 15° E., with a high easterly dip. It has been opened along its strike for a distance of nearly 100 yards up and down the slope of the mountain. The lowest opening is an old tunnel run in on the "vein" for drainage and development purposes. A shaft started higher up the hill to meet this old tunnel was never completed. At the time of visit a block of mica weighing nearly 100 pounds was found in the bottom of the shaft and several other fine blocks of mica were found within 3 feet of the surface in a cut east of the shaft. The latter material may have been drift from the outcrop of the "vein" above, though it probably belonged to a second "vein" parallel to the first. A corresponding "vein" has been opened by an incline lower down on the hill above and east of the drainage tunnel. The mica from this mine has a rich "ruby" to "rum" red color and is of excellent quality for stove purposes.

Hensley mine.—The Hensley mine is on Pigpen Creek about 2 miles west of south of Green Mountain. It is said that there were ancient workings at this mine. It was operated by the Hampton Mining Company in 1906, when the accompanying notes were taken. The mine was also worked at earlier dates by white people. The country rock is mica gneiss, with north-south strike and a nearly vertical dip. The pegmatite is conformable, or nearly so, with the schistosity of the inclosing rock. It occurs in lens-shaped masses 3 to 4 feet thick. The mine has been opened by two shafts, 40 and 45 feet deep and 15 feet apart, each one evidently having been sunk on a rich lens. In the space between the shafts, partly worked out, the overlapping of two lenses was well shown. (See fig. 68.) The gneiss and schist walls bend around the lenses. Fifty feet south of the shafts an open cut exposed a lens $2\frac{1}{2}$ feet thick and about 15 feet long lying in the gneiss. Some blocks of mica many pounds in weight have been found. Part is clay and iron stained near the surface and is used for electrical purposes, and part has a clear amber color and is suitable for stove use.

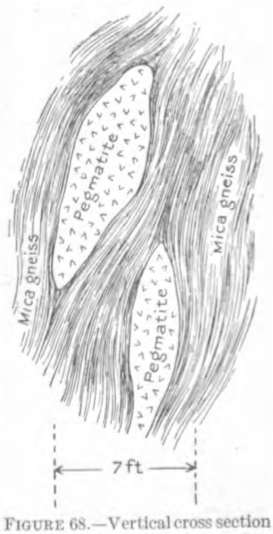


FIGURE 68.—Vertical cross section of pegmatite at Hensley mine, Yancey County, N. C.

Young mine.—The Young mine is about 2 miles west of Booneford and 100 yards west of South Toe River. The mine has been opened by cuts, pits, tunnels, and shafts covering a width of more than 50 feet and for a distance of more than 200 feet. The workings extend from the south side over the top to the north side of a ridge about 100 feet high. The mine has been operated at several different times, the last time by the J. E. Burleson Company in 1904–5. The country rock is hornblende gneiss, biotitic near the contact with the pegmatite. The pegmatite outcrop crossing the creek on the south side of the ridge is about 100 feet wide. The strike of the formations is about N. 35° E. and the dip 75° SE. Streaks or horses of mica schist are included in the strike of the pegmatite and are parallel with it. The mica occurs in streaks parallel with these bands of schist, and the latter are left as walls to the workings in places. There is much small-sized mica in the "veins" and some sheets of large size are reported to have been found. The quality is good and the mica is said to be especially fitted for electrical purposes.

MITCHELL COUNTY.

Knob mine.—The Knob mica mine is a little more than 2 miles northeast of Spruce Pine. The pegmatite is inclosed in biotite gneiss or schist, with which it is roughly conformable. It strikes about N. 45° E. and dips about 40° SE. The pegmatite is coarsely crystallized next to the hanging wall and grades into fine-grained pegmatite or

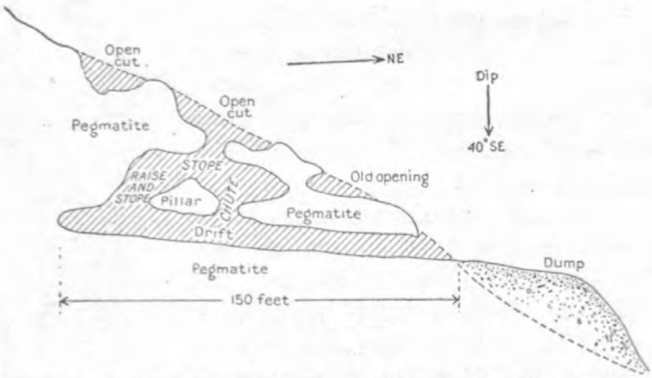


FIGURE 69.—Section in plane of pegmatite at Knob mine, Mitchell County, N. C.

coarse granite on the lower side. Only the coarse pegmatite, called the "vein," is mined; this pinches and swells between 1 and 4 feet in thickness. The mine was first worked by open cuts on the outcrop and shallow inclines. Later a drift was run about 150 feet from the outcrop lower down on the hillside, and portions of the "vein" were stoped out to the open cut above. Figure 69 is a section in the plane of the "vein" and shows the nature of the work at the time of visit. The mica has a dark-green color and is "specked," some abundantly, with dendritic spots of magnetite. Some crystals of large size are found, and one weighing 165 pounds was obtained at the time of visit in 1904. This block measured roughly 12 by 20 inches and was 30 inches thick. The mica was split and graded at the mine and shipped to electrical manufacturers. The splitting and rough trimming were done chiefly by women.

W. W. Wiseman mine.—The Wiseman mine is 2 miles northeast of Spruce Pine, on Beaver Creek. According to Mr. Mart Wiseman it was opened by James Wiseman and John Pendley in 1875. These men removed $2,000 or $3,000 worth of mica in one year's work. Later the mine was operated by Lum Blalock and Luke Lewis, and still later by other parties. About 1890 the mine went into the hands of the Southern Mica Company. The early workings consisted of a shaft carried down 30 feet and a tunnel 40 feet long along the vein.

At the time of visit (1904) the old workings had caved in badly, leaving a pit resembling an old open cut. The more recent workings of the Southern Mica Company were still open, however. A crosscut tunnel some 250 feet long had been driven into the "vein," along which drifts with extensive stoping were run. The country rock is highly schistose mica gneiss which has a varied dip and strike where it is cut by the tunnel. Several feet before the "vein" was reached the tunnel encountered coarse granite or fine-grained pegmatite, which grades into coarse pegmatite near the "vein." The coarse granite cuts across the schistosity of the gneiss, which trends N. 15° W. and has a 25° W. dip at the contact, whereas the granite has a strike more nearly east and west. Figure 70 shows the position of the workings and the relations of the rock formations. The crystallization of the pegmatite as exposed in the walls of the drift is very coarse. Crystals of orthoclase feldspar 2 and 3 feet square had been cut through and the candle light reflected from the cleavage faces exposed outlined their shapes well. This mine is reported to have yielded large blocks of mica, one weighing about 2,000 pounds. Samarskite is said to have been found in masses of many pounds weight and broken up and lost before its nature was known.

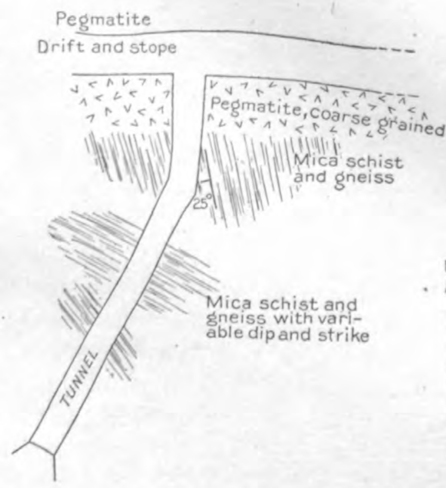


FIGURE 70.—Plan of later workings at the W. W. Wiseman mine, Mitchell County, N. C.

Charlies Ridge mine.—The Charlies Ridge mine is 1½ miles south of west of Plumtree and one-half mile west of Spear, about 200 yards southeast of the Justice mine. It was discovered about 1882 or 1883 by Ben Aldrich and worked by him for about six months. It has been operated at different times by Samuel Landers, Colonel Irby, and W. W. Irby. During 1905 and 1906 it was being reopened by A. Miller, C. W. Wisler, and J. W. Walters. The earlier work consisted of three tunnels and some pits. The new work consisted of a tunnel about 230 feet long at the time of visit. This tunnel was expensive, being run through very hard rock at the rate of about 3 feet a week and not being driven in a straight course. A plan of the workings and position of the pegmatite is shown in figure 71. The elevation of the new tunnel is given as zero, and the other three were run in about 40, 55, and 65 feet higher up and to the east. The new tunnel rises nearly 30 feet from its mouth to its head, thus losing much of the advantage gained through the position of its starting point. From measurements taken for the benefit of the miners it was found that the tunnel would have to be driven about 80 feet farther, if on a level, and in a direction S. 40° E., to strike the "vein."

The country rock is biotite gneiss, whose dip and strike vary, though in general the strike is northeasterly and the dip southeasterly. The pegmatite is large and is richer in mica near its walls than in the

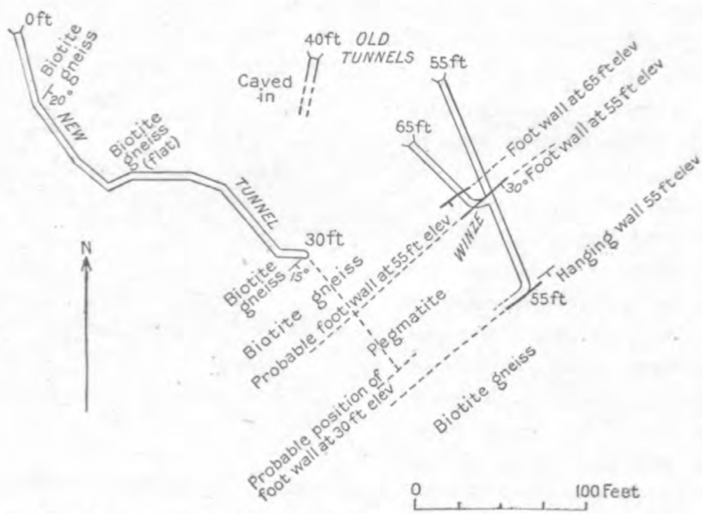


FIGURE 71.—Plan of Charlies Ridge mine, Mitchell County, N. C.; figures give elevations above mouth of new tunnel. The position of the pegmatite is shown on the 55 and 65 foot levels; also the probable position at the level of the end of the new tunnel.

interior. There is a streak of highly foliated biotite schist 3 to 6 inches thick along the walls.

Plumtree mine.—The Plumtree mine is one-half mile east of Plumtree, on Plumtree Creek. It was discovered by C. W. Burleson about 1870 and worked by him for about six months. It was later worked by Colonel English, Colonel Rorison, W. W. Avery, and others, and after a period of idleness was reopened again by the Burleson Brothers in 1906. The mine was operated by an open cut on the outcrop with a 30-foot incline and a tunnel or drift on the "vein" from a lower level. The country rock is mica gneiss interbedded with hornblende gneiss, and the wall rock is mica gneiss. The pegmatite is conformable, or approximately so, with the inclosing formations and strikes about N. 25° W., with a dip of 10° to 25° NE. It is from 18 inches to 4 feet thick. The mica streak lies near the hanging wall and in places is separated from the wall by a quartz vein 3 to 5 inches thick. The crystals of mica are reported to be of good size, running up to 40 and 50 pounds in weight. Some of them are badly crushed and crumpled and suitable for grinding purposes only. The quality of the sound crystals is good. The sheets have a greenish cast and are in places slightly "specked."

Johnson mine.—The Johnson mine is 2 miles east of Plumtree, on Plumtree Creek. The country rock at this mine is hornblende gneiss, biotitic near the contact with the pegmatite. The pegmatite is conformable, or nearly so, with the inclosing gneiss, which lies nearly flat in places and has gentle rolling folds in other places. The pegmatite varies from a few inches to 7 feet in thickness and is reported by the miners to be richest in mica where it is between 2½ to 4 feet thick. The main opening consists of a tunnel about 100 feet long, running N. 30° W. for 80 feet and then due north for 2 feet. For the last 30 feet of this tunnel the pegmatite is 7 feet thick and carries but little mica. Other tunnels have been run in different positions, following the directions in which the best mica was found. The rolling structure of the formation can be seen from the two dips and strikes. At the entrance to the main tunnel the strike was about N. 70° E. and the dip 20° N. A little way in the rock was nearly flat, and near the end of the tunnel the strike was due north and the dip 15° W.

The mica obtained from this mine is of the finest quality, with a rich "rum" color. One block is reported to have been found worth over $100.

WATAUGA COUNTY.

Dobbins mine.—The Dobbins mica mine is about 2 miles north of west of Elk Crossroads. It was operated extensively about 1890 and on a smaller scale about ten years later by the Blue Ridge Mica Company. There are two sets of workings about 250 yards apart, one at the foot of the hill and the other on the top of the ridge to the northeast. The work near the road consists of five tunnels, with two shafts and other openings of "groundhog" nature. The tunnels have been run in at different levels on the hillside, in a space about 70 feet wide, showing a large pegmatite formation. These tunnels have directions varying from N. 25° to 45° E. and roughly show the trend of the pegmatite. The country rock is biotite gneiss and strikes between N. 30° and 40° E., with a nearly vertical dip. The pegmatite is conformable, or approximately so, with the inclosing gneiss. Portions of pegmatite rich in small mica were exposed in some of the workings, but in others there was little or no mica. The openings on the ridge consisted of three shafts and tunnels on each side of the summit. The openings were confined to a belt about 100 yards long in a direction N. 35° E. and about 40 feet wide. One deep shaft has been well timbered and was in a good state of preservation. The other openings had caved badly. But little mica had been left around these workings. The mica seen at the openings along the road was mostly of a dark-brown to greenish-brown color. Part was "specked" and in "wedge" shaped blocks with the "A" structure. Some clear sheets were seen with good cleavage, but of rather dark color.

ASHE COUNTY.

Hamilton mine.—The Hamilton mine is on the west slope of a mountain 2 miles northwest of Beaver Creek. It was reopened by the Johnson-Hardin Company in 1907, since the accompanying notes were taken. The deposit was opened by two tunnels run into the hillside along the vein. In the upper and earlier one a shaft or winze was sunk 35 feet from a point about 20 feet in from the mouth of the tunnel. From the bottom of this shaft a curved tunnel was cut on vein material. The second tunnel was run at a lower level for a distance of 75 feet about south and did not connect with the upper one. This tunnel did not follow the pegmatite closely but seemed to cut across its strike at a small angle. The strike of the pegmatite appeared to be about N. 10° E. and the dip nearly vertical or to the east. The pegmatite is composed of feldspar and quartz in fairly coarse aggregates, with both muscovite and biotite in good-sized sheets. The muscovite mica is of excellent grade and has a clear light to dark "rum" color. The larger blocks of mica yielded sheets of 6 by 8 or 8 by 10 inches, but the principal production was in smaller sizes. The biotite occurs in sheets of nearly equal size and some of it is intimately intergrown with muscovite, the two having the same cleavage plane.

North Hardin mine.—The North Hardin mine is in a ridge about 1½ miles west of Beaver Creek. It has been worked on a large scale and more systematically than is usual for mica in North Carolina. The mine was operated by two open cuts and other pits, three crosscut tunnels to the "vein," two shafts, and considerable drifting and stoping on the vein. These workings have proved the continuity of the pegmatite for a length of over 100 yards and shown the thickness to vary from 3 to 8 feet. The country rock of the region is hornblende gneiss, but the mica deposit occurs in a smaller belt of biotite (probably granite) gneiss. The strike of the pegmatite is about N. 20° E. and the dip 75° to 80° E. At a place about 80 yards north of the main workings a shallow shaft was sunk in line with the "vein" on a small streak of pegmatite 18 inches thick, which was probably the main "vein" pinching out. Figure 72 shows the extent of the work open for examination at the time of visit. A large part of the stoping and drifts had caved in and could not be seen. The greater part of the vein above the tunnels shown in the figure had been removed, however, and future work should be directed to vein matter between old workings and to lower depths, easily attained with facilities for draining. Tunnel No. 3 is probably 50 feet higher than No. 1. The mine produced a large quantity of small block mica, yielding sheets 1 by 2 and 3 by 4 inches. A number of larger blocks, yielding sheets 6 by 8 and more inches square, were found with the smaller material. Many small blocks of mica and one crystal over 10 inches thick and a foot wide were seen in the "vein," embedded in feldspar. The mica has a beautiful clear "rum" color and is of the best grade. Most of the blocks yield sheets of per fect quality.

South Hardin mine.—The South Hardin mine is near the top of a small mountain or hill about 1½ miles southwest of Beaver Creek. This mine was first opened by small pits, trenches, and a tunnel along the "vein." The surface workings were at the summit of the hill and the tunnel on the outcrop about 40 feet lower down to the northeast. The mine was later operated by a 30-foot shaft near the top of the hill and an open cut about 75 feet long and 10 to 20 feet deep on the "vein."

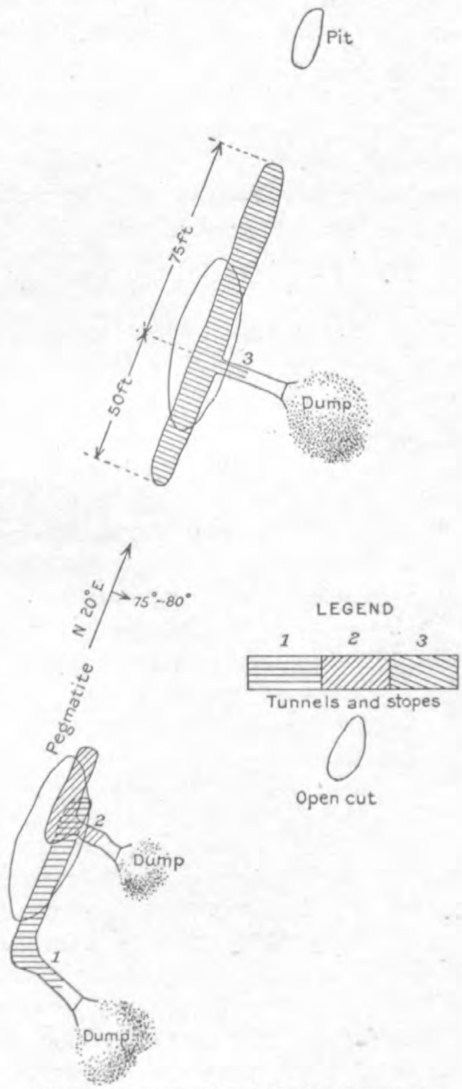


FIGURE 72.—Plan of North Hardin mine, Ashe County, N. C.

The country rock of the region, like that at the North Hardin mine, a mile to the northwest, is hornblende gneiss. The mica-bearing pegmatite is inclosed in a smaller mass of biotite mica gneiss included in the hornblende gneiss. The pegmatite is conformable with the schistosity of the inclosing formations, which strike due northeast and dip 50° SE. at this point. The pegmatite is about 7 feet thick as exposed at the surface. The interior is fine grained or like coarse granite, whereas along the walls the crystallization is much coarser. The principal mica yield is reported to have come from the foot wall, along which massive quartz streaks up to 2 feet thick were found. It is said that the crystallization of the pegmatite was coarser below a depth of 15 feet and the quantity of mica in it larger than near the surface. The color of the mica obtained was a clear "rum" and the quality the best.

The quartz streaks along the foot wall of the pegmatite contained beryl crystals from less than an inch to 6 or 8 inches in diameter. These crystals were of good golden and aquamarine color, though cloudy and only translucent. It was found they made very pretty gems for scarf pins, cuff buttons, etc., when cut en cabachon.

WILKES COUNTY.

Joel Triplett mine.—The Triplett mica mine is near Hendricks on Stony Fork, 16 miles from Wilkesboro. There are three mica prospects on this property, one of which was opened several years ago by a tunnel 40 feet long. A pegmatite about 8 feet thick had been exposed approximately conformable with the mica gneiss country rock. The latter had a strike of N. 30° E. and a dip of 35° SE. and contained numerous small lenses and masses of quartz and pegmatite throughout. Mica was segregated in various small-sized blocks along the walls of the pegmatite. Some 50 pounds of sheeted and cut mica were seen. The sheets ranged in size from 2 by 2 to 4 by 4 inches. In quality the mica varied from clear sheets with good cleavage to smoky or "specked" and "A" mica. The color of the best was rather dark greenish brown in sheets a sixteenth of an inch thick or more.

RUTHERFORD COUNTY.

Isinglass Hill mine.—The Isinglass Hill mine is on the Southern Railway about 3½ miles north of Rutherfordton. A pegmatite formation over 30 yards thick has been found to carry mica in certain parts. The country rock is hornblende gneiss, badly folded and contorted, and the pegmatite is roughly conformable with it. The strike is east of north and the dip in general nearly vertical. The pegmatite near the mica workings is many yards thick and in a railroad cut 200 yards to the north shows only as small streaks, probably stringers from the main mass after it had forked into smaller branches. The pegmatite has been traced over 200 yards to the south by prospect shafts, but it is not known how thick it is at these points. Mica was found most plentifully in the portion where the open cuts are shown in figure 73. It is principally associated with a massive quartz streak in this place. The depth to which the mica workings were carried could not be ascertained because they had caved in badly, owing to the soft, decomposed nature of the rocks. The mica is in large part badly "specked" with magnetic iron. To judge from the large quantity of sheets 2 to 5 inches in diameter left on the dump, mica must have been very plentiful where found. Much of this waste mica was either "A" or "wedge," however.

Since the operations for mica were suspended the deposit has been examined for its value as a kaolin mine, and for this purpose some of the tunnels on the east and shafts to the south were made. Good kaolin was found in some of the openings, but its extent had not been adequately proved at the time of visit. The following analysis of the kaolin, made by T. W. Smith, commercial chemist, Indianapolis, Ind., was furnished by Mr. Olive, owner of the mine:

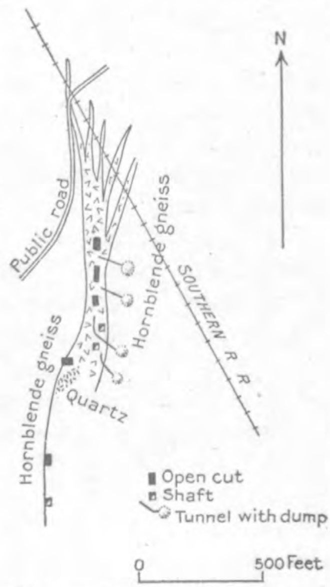


FIGURE 73.—Plan of workings and probable shape of the pegmatite in Isinglass Hill mine, Rutherford County, N. C.

Analysis of kaolin from Isinglass Hill mine, N. C.

SiO_2	44.12
Al_2O_3	39.50
CaO	.08
MgO	Trace.
FeO	.08
Alkalies	.81
Ignition	14.53
	99.12
Rational analysis:	
Clay substance	95.59
Quartz	3.39
Feldspar	1.02
	100.00

CLEVELAND COUNTY.

M. M. Mauney mine.—The Mauney mica mine is about 1 mile southwest of the old Camp Call post-office, or 9 miles northwest of Shelby. It was first worked over thirty-five years ago and has not been worked within twenty years. The country rock is much crumpled mica schist-gneiss with a general strike of about N. 45° W. The pegmatite cuts across this with a strike of N. 20° E. and a nearly vertical dip. The part exposed in the old workings is composed of a quartz band about 5 feet thick with 2 to 4 feet of feldspar, quartz, and mica on each side. The mine was worked by an open cut 20 feet deep and 40 feet long, and a shaft with tunnels, both now fallen in. The mica streak was all removed on the west side of the quartz ledge in the bottom of the open cut and only partly so on the east side. The mica is of fine quality, with a clear "rum" color. Specimen sheets measuring a foot across have been kept in the Mauney home.

S. J. Green mine.—The Green mine is about 7 miles northwest of Shelby. The mine was opened in the seventies and operated again at later dates. The workings have fallen in badly and but few notes were obtained. The country rock is mica schist-gneiss striking north with a dip of 70° W. The vein strikes about N. 70° E., as shown by the position of eight or ten shafts and pits with tunnels. These workings are all within a distance of about 60 yards of one another. Streaks of massive quartz up to 3 feet thick were encountered in the pegmatite in the workings. In one of the workings the mica was obtained from the north wall of one of the quartz ledges. The pegmatite is rich in feldspar, more or less kaolinized in places. The mica is of good quality and has a clear "rum" color.

Indian Town and Casar mines.—The Indian Town and Casar mines are in the north end of Cleveland County, 3 miles north of east of Casar and on the southeast side of Casar, respectively. There is so much similarity in the occurrence in each group of mines and so little to see of the formation at any one of the separate mines that a general description will answer for all. The Indian Town mines cover an area of over a square mile and consist of a dozen or so small open cuts or shallow shafts which have caved in badly. The same may be said of the deposits near Casar and of one near Carpenter Knob, 5 miles east of Casar. The country rock of this general region is a highly schistose gneiss with mica, cyanite, and garnet as constituent minerals. The gneiss has been much folded and crumpled over the whole region and has been intruded by granite masses in places. The pegmatite bodies, opened for mica, appear to cut across the schistosity of the gneiss as a general rule, though in some places they lie conformably with it. They range in thickness from 2 to 15 feet and are rather irregular in shape. In most of the deposits masses of quartz are encountered, generally in the form of ledges or veins within the pegmatite. The occurrence of large bodies of feldspar or its alteration product, kaolin, with the mica is not common. Much of the mica obtained in this region is of excellent quality and has a rich "rum" color. Part has "A" markings, but large sheets have been cut from the portion between the "A" lines.

LINCOLN COUNTY.

Thomas Baxter mine.—The Baxter mica mine is about three-fourths of a mile from the southwest corner of Lincoln County, on the old Rutherfordton road. It is probably the oldest mine in the county and is reported to have been opened before 1870. The workings have nearly all fallen in, and little could be determined of the formation. There were six to eight shafts and cuts with tunnels. One shaft is said to have been 65 feet deep, with good mica in the bottom. The ground-water level in a well near the mine was about 35 feet below the surface. The workings fall within an area about 50 yards wide and 75 yards long in a direction north of east. The country rock is much-folded mica schist-gneiss. A large quartz vein or ledge outcrops in a direction N. 70° E. through the workings. The mica is of the best quality, splitting well, and has a beautiful clear "rum" color. Large quantities of weathered small sheet mica 1 to 2 or 3 inches in diameter are scattered around the mine. It is said that the mine was a large producer, including many pounds of large sheets, as 8 by 10 and 10 by 12 inches.

M. M. Hull mine.—The Hull mine is about 2½ miles northeast of Hulls Crossroads. This mine, which was opened about 1891, is sometimes called the Rock Cut mine. The work consists of a cut 40 feet long, 20 feet deep, and 5 feet wide. The pegmatite strikes N. 70° E. and is nearly vertical. It cuts across the cyanitic mica gneiss country rock, which strikes N. 10° E. and dips 50° SE. Bunches of small mica are still left in the walls. The color and quality of the mica are of the best, and some sheets 10 by 14 inches are reported to have been found.

John Dillinger mines.—The Dillinger mines, of which No. 1 is 2 miles south of Henry on the roadside and No. 2 is on a branch one-fourth mile west of the same road, were worked in 1905 and 1906 by the Cawood Mica Company. At each mine the country rock is much folded cyanitic mica gneiss. The pegmatite streak in each is irregular and has an east-west strike. Each mine was opened by a cut from 18 to 20 feet deep. In the No. 1 mine much of the mica found was "A," but of good color and with some clear portions. In the No. 2 mine the pegmatite had quartz ledges in it and the most mica was found alongside of these. Beryl was also reported as found in this mine.

STOKES COUNTY.

Joe Hawkins mine.—The Hawkins mica mine was first opened about 1890 by people living in the county and during 1903 was again operated by the Empire Mica Company, of New York. It is about 2½ miles southwest of Sandy Ridge, in the northeastern part of

Stokes County. The mica occurs in an irregular massive pegmatite formation, in which feldspar and quartz form large separate masses. The pegmatite varies from 6 to 12 feet in thickness, as exposed in the workings, and is approximately conformable to the inclosing mica gneiss country rock. The latter strikes a little north of east and dips about 35° N. Much of the quartz of the pegmatite occurs in bands or sheets, from a few inches to about 2 feet in thickness, lying parallel with the strike of the pegmatite. But little mica had been left in the "vein" from the last work, and much of that seen was of the "wedge" and "A" nature, with good portions between the "A" structure lines. Some of this wedge and distorted mica included rough garnets, either in crystals or flattened between the laminæ. The workings consist of two open cuts, with an incline on the pegmatite from one, and three shafts 20 to 30 feet deep with tunnels connecting them. In all there are nearly 150 feet of tunnels and incline. Figure 74 gives a general plan of the workings.

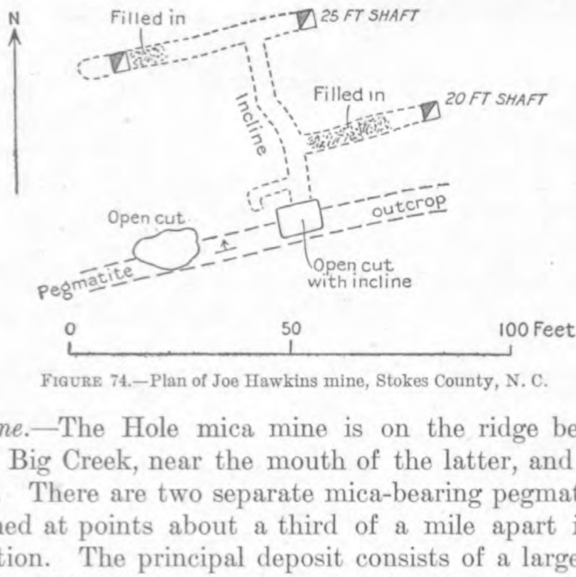


FIGURE 74.—Plan of Joe Hawkins mine, Stokes County, N. C.

Hole mine.—The Hole mica mine is on the ridge between Dan River and Big Creek, near the mouth of the latter, and near Tulip post-office. There are two separate mica-bearing pegmatites at this mine, opened at points about a third of a mile apart in an east west direction. The principal deposit consists of a large pegmatite over 20 feet thick, striking nearly east and west with a dip of 30° N. As exposed in the open work on the outcrop and small inclines, the pegmatite is composed of three bands or veins of massive quartz from 4 to 6 feet thick, with two beds of feldspar 4 to 7 feet thick between them. It is said that another feldspar band was developed beneath the lower quartz vein exposed at the time of visit, but this was covered with rubbish and could not be examined. The quartz and feldspar bands or veins are parallel and dip with the pegmatite to the north. The feldspar has kaolinized to a large extent and has been removed from the two veins exposed in inclines 10 and 20 feet deep. There were smaller masses and streaks of quartz 1 to 10 inches thick in the large feldspar streaks. Figure 75 is an ideal cross section of the pegmatite. The pegmatite can be traced a number of yards along the outcrop by massive white quartz bowlders. Mica occurs through the feldspar masses and along the contact with the quartz streaks. The mica is partly of the "A" variety, and a 20-pound block of such mica was seen in the face of one of the veins. The mica has a brownish or smoky color.

At the other outcrop a few small open cuts and an incline 20 feet deep have proved the pegmatite for about 200 feet along a steep hillside. The pegmatite here is conformable with the mica gneiss

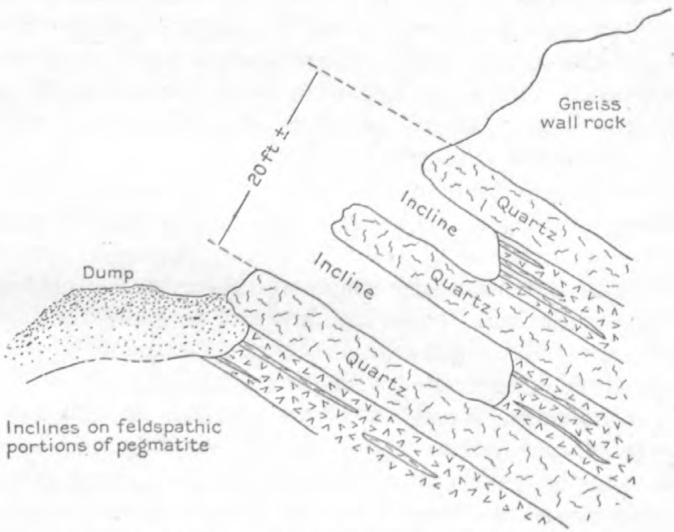


FIGURE 75.—Ideal cross section at Hole mine, Stokes County, N. C.

country rock and is several feet thick. The dip and strike are very much the same as at the deposit first described. The feldspar of the pegmatite has not been kaolinized, however, and the formation is fairly hard. Only small mica blocks were seen in the hard rock, and this mica was of clear dark-green color, considerably ruled.

ORIGIN.

Mica of commercial size in North Carolina occurs only in pegmatite. There has been considerable difference of opinion concerning the origin of this rock in different regions, some writers arguing for intrusion as an igneous magma, others for deposition from solution. One group maintains that pegmatite formed as dikes, the other that it formed as veins. Still other authors consider pegmatite to be the product of aqueo-igneous processes in which there are all gradations between the conditions of a magma and those of a solution. Accordingly, it would be impossible to draw a sharp line between pegmatites formed as dikes and those formed as veins. In some places the nature of the pegmatite and its relation to the accompanying rock are such that it may be stated with a fair degree of certainty to which class the deposit belongs.

In the mica-bearing pegmatites of North Carolina there are features that may be interpreted as showing an intrusive origin in one place and a solution deposit in another place. On the other hand, a large number of the deposits possess features characteristic of both dikes and veins, so that it is not possible to assign one method of formation or the other. It is probable that the greater number of the pegmatites opened for mica in North Carolina approach conditions of vein formation more closely than they do those of dike formation. This is in contrast with the mica-bearing pegmatites of South Dakota,[a] which, in the greater number of places, are thought to possess features characteristic of dikes rather than of veins.

Features observed in pegmatites that may indicate vein origin are the presence of quartz veins or sheets oriented parallel to the walls; the similarity of these quartz veins or sheets to ordinary quartz veins in the mica region; horses of wall rock in sheetlike bodies lying parallel to the walls (by intrusion such sheets would tend to be turned or bent at an angle to the walls); the occurrence of pegmatite in small lens-shaped bodies; balls, veinlets, and other replacement deposits, some of them entirely disconnected with other pegmatite masses. The following conditions are possible evidence of intrusion: The occurrence of irregular-shaped horses and distorted sheetlike horses without parallelism to the walls; a typical coarse granite texture and its persistence through a considerable distance; a bending of the schistosity of the inclosing rock around pegmatite bodies without evidence of replacement (this may also take place around deposits from solution in which the force of crystal growth has distended the wall rock).

[a] Mica deposits of South Dakota: Bull. U. S. Geol. Survey No. 380, 1909, pp. 382-397.

SUPPOSED DEPOSITS OF GRAPHITE NEAR BRIGHAM, UTAH.

By Hoyt S. Gale.

Reported deposits of graphite near Brigham, Utah, have recently been the subject of considerable interest in a more or less local way. Prospects situated on Threemile Creek, between the settlements of Brigham and Perry, Boxelder County, Utah, were visited by the author in October, 1909, and several samples representative of the material that had then been exposed were collected. These samples have been analyzed by Dr. Chase Palmer in the Geological Survey laboratory.

The deposits near Brigham form a part of a series of metamorphosed sediments, presumably of pre-Cambrian age. The associated rocks consist of slates and schists, graywackes, conglomerates, and quartzites, all more or less sheared and contorted. Some beds of black, somewhat foliated schist are included in this series, and these beds are apparently derived through metamorphism from strata containing carbon, probably originally in the form of organic remains, if organic material may be assumed to have existed in rocks of pre-Cambrian age. The carbonaceous schists outcrop near the channel of Threemile Creek, having a general east-west strike and showing at intervals for at least three-fourths of a mile. The carbonaceous beds exposed in the shallow prospects appear to be at least 15 or 20 feet in thickness, and as they evidently represent an original stratum of the sedimentary series, it is quite probable that they may prove fairly persistent both horizontally and in depth throughout the area in which the outcrops occur. The carbonaceous schist shows a black lustrous polish resembling that of graphite, especially in joints or on the foliation of the rock. When pulverized, however, the substance lacks the smooth, greasy feeling of pure graphite, but much of the material selected as most promising for commercial use appears to be free from coarse sand or grit.

An average sample representing 7 feet 4 inches of the beds exposed in the main prospect was analyzed, giving the following results:

Analysis of average sample of supposed graphite from deposits near Brigham, Utah.

Moisture and volatile matter	3.34
Fixed carbon (by difference)	3.48
Ash	93.18
	100.00

Another sample collected at random from a more foliated or schistose bed associated with a large vein of quartz about three-fourths of a mile farther up the canyon gave the following test:

Analysis of supposed graphite from deposits near Brigham, Utah.

Moisture	1.24
Volatile matter	9.97
Fixed carbon (by difference)	5.48
Ash	83.31
	100.00

As these analyses ran unexpectedly low, test was made of a selected piece of the richest-looking material. The result of this test is essentially similar to the others:

Analysis of selected sample of supposed graphite from deposits near Brigham, Utah.

Moisture and volatile matter	5.03
Fixed carbon (by difference)	5.59
Ash	89.38
	100.00

In all these tests the carbon burned off in the flame of an ordinary Bunsen lamp without the use of the blast, apparently indicating that the substance is more of the nature of an impure coal than of graphite. The ash derived from the combustion of these samples is essentially clay of a light-gray color, showing it to be free from whatever carbon it originally held.

Material resembling the deposits near Brigham in appearance is used in the manufacture of paint and also for foundry facings. This usually contains, however, over 20 per cent of carbon in the form of true graphite. The Brigham material, although containing little or no graphite, may possibly prove of value as a paint pigment. Its value for fire-resisting purposes is questionable.

SURVEY PUBLICATIONS ON MISCELLANEOUS NONMETALLIC PRODUCTS—ASBESTOS, BARITE, FELDSPAR, FLUORSPAR, GRAPHITE, MICA, QUARTZ, ETC.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various nonmetallic mineral products. The government publications, except those to which a price is affixed, may be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

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STERRETT, D. B. Mica deposits of western North Carolina. In Bulletin 315, pp. 400–422. 1907.

——— Meerschaum in New Mexico. In Bulletin 340, pp. 466–473. 1908.

——— Mica deposits of South Dakota. In Bulletin 380, pp. 382–397. 1909.

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