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Part I.—METALS AND NONMETALS EXCEPT FUELS

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ILLUSTRATIONS:

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1912.

PART I. METALS AND NONMETALS EXCEPT FUELS.

DAVID WHITE, *Chief Geologist.*

INTRODUCTION.

This volume is the eleventh of a series that includes Bulletins 213, 225, 260, 285, 315, 340, 380, 430, 470, and 530, "Contributions to economic geology" for 1902, 1903, 1904, 1905, 1906 (Pt. I), 1907 (Pt. I), 1908 (Pt. I), 1909 (Pt. I), 1910 (Pt. I), and 1911 (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) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of which are to be published later in more detailed form.

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 localities or 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.

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.

Since 1905 the annual economic bulletin has been printed in two parts, the second part comprising papers on mineral fuels. These volumes for 1906, 1907, 1908, 1909, 1910, and 1911 are Bulletins 316, 341, 381, 431, 471, and 531. Bulletin 541 will form Part II of the "Contributions" for 1912.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, and 542.

GOLD AND SILVER.

AURIFEROUS GRAVELS IN THE WEAVERVILLE QUADRANGLE, CALIFORNIA.

By J. S. Diller.

INTRODUCTION.

Few mining regions in California have attracted so much general attention and held it for so long a time as the Klamath Mountains of Siskiyou and Trinity counties, in the northwestern part of the State. The placers along Trinity and Klamath rivers were developed early in the gold rush and have been worked with varying energy to the present time. The La Grange mine, which is one of the largest hydraulic placers in the world, is now in the height of its activity.

In order that an account of mining in the Weaverville quadrangle may have its proper setting it is necessary to consider the general relations of the mountain ranges in the adjacent portions of California and Oregon.

THE KLAMATH MOUNTAINS.

GENERAL RELATIONS.

The mountain belt of the Pacific coast in California and Oregon includes a number of distinct ranges whose distribution and composition are in part illustrated by the accompanying geologic map (fig. 1). On the north are the Cascade Range and the Coast Range of Oregon, separated by the Willamette or Sound Valley as far south as Eugene. On the south are the Sierra Nevada and Coast Range of California, separated by the great valley of California. About the western part of the California-Oregon boundary, where all these ranges appear to meet, there is a distinct group of mountain ridges and peaks extending from a point north of the mouth of Rogue River in Oregon to Mad River in California. This group constitutes the Klamath Mountains. It embraces the South Fork, Trinity, and Salmon mountains of California and the Siskiyou and Rogue River mountains of Oregon.

These ranges are distinguished largely from geologic data, as will be more readily understood by referring to the map (fig. 1). The symbols on the map indicate in general the geologic age of the sedimentary rocks of the Klamath Mountains. To illustrate their areal distribution more clearly, all details and small areas have been omitted and outlines have been broadly generalized to cover large areas of igneous rocks. The map shows at a glance that the forma-

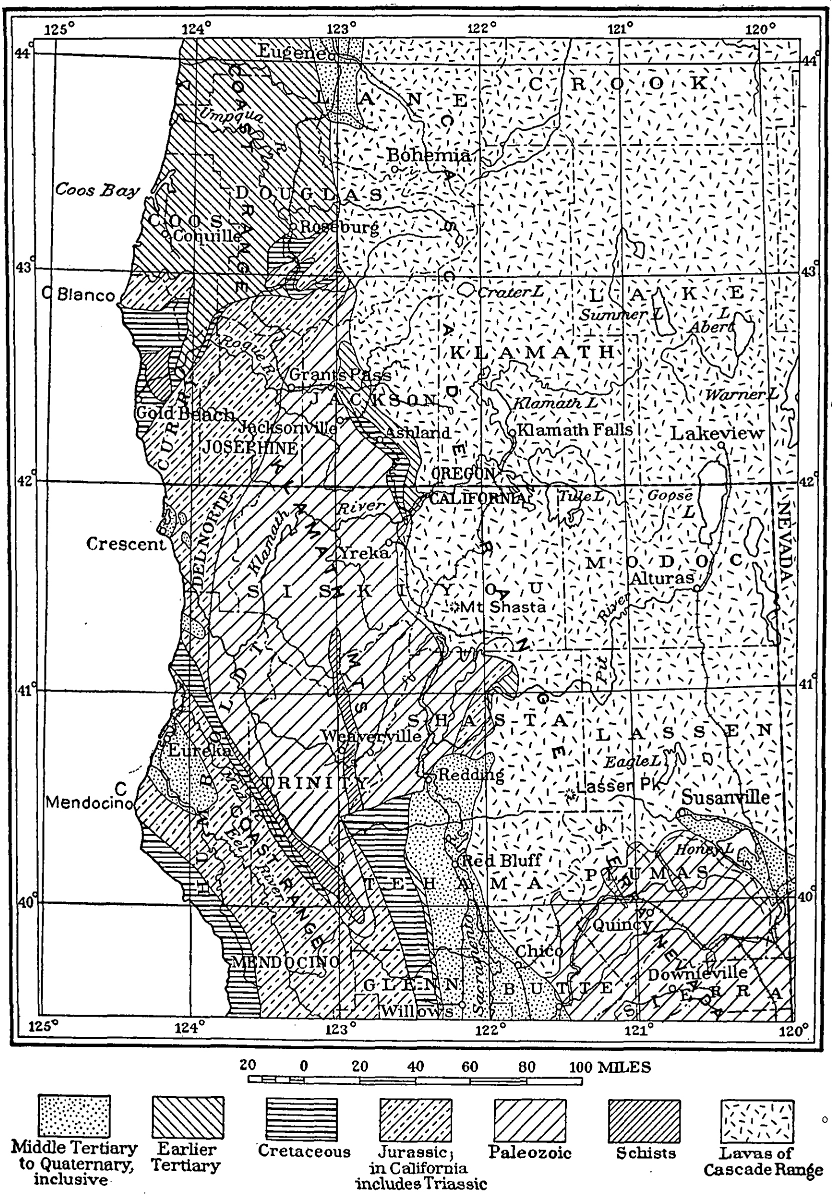


FIGURE 1.—Geologic map of the Klamath Mountains and adjacent ranges, California. Formations grouped and details generalized or omitted.

tions outlined occur mainly in the northwestern part of California, but they cover also a small area in Oregon.

The Klamath Mountains and the Sierra Nevada are composed in the main of essentially the same formations, and in the southern part of the Klamath Mountains the formations and lines of structure trend northwest and southeast, toward the Sierra Nevada, but in the northern portion they trend southwest and northeast, toward the Blue Mountains of eastern Oregon. Besides this general alignment of the formations of the Sierra Nevada, Klamath, and Blue mountains, their mineral resources are similar, a feature in which they are strongly contrasted with the Cascade and Coast ranges in Oregon and California.

GEOLOGIC HISTORY.

Little is known of the early geologic history of the Klamath Mountain region, yet it is evident that in pre-Devonian,[1] possibly in Algonkian [2] or late Archean [3] time the region was beneath the ocean, receiving the sediments from which the mica schist and intercalated crystalline limestones of South Fork Mountain and the Salmon Mountains north of Weaverville were formed.

The extensive development of Devonian and Carboniferous shales, sandstones, cherts, and limestones in the Klamath Mountain region shows that at least a part of the region continued beneath the sea through the whole or the greater part of the Paleozoic era, but the incompleteness of the succession and the discordance among the formations bear evidence of considerable earth movements at several times during the long period of sedimentation, culminating in the great mountain-building epoch at the close of the Jurassic. At times, too, while these sedimentary rocks were forming, especially before the Middle Devonian and during the later part of the Carboniferous and the greater portion of the Mesozoic, volcanoes were active in the region, giving rise to extensive sheets of contemporaneous lava and tuff intermingled with the sedimentary rocks and in many places covering them.

About the close of the Jurassic period this complex of sedimentary and igneous rocks was compressed, folded, faulted and uplifted to form the Klamath Mountains, and at the culmination of this process the mass was intruded by coarse granular bodies of plutonic rocks, such as granodiorite, gabbro, and peridotite, and by many dikes having a wide range in chemical and mineral composition.

As a consequence of this intense, varied, and long-continued igneous action, the heated circulating waters finally formed many ore deposits within the intruded masses or near their contacts. These deposits may have been enriched later by descending waters from the zone of oxidation.

Erosion and subsidence during the Cretaceous period reduced the Klamath Mountains to sea level, and for a brief interval they may

[1] Diller, J. S., Am. Jour. Sci., 4th ser., vol. 15, 1903, p. 343.
[2] Hershey, O. H., Am. Geologist, vol. 27, 1901, p. 245.
[3] Hershey, O. H., Am. Jour. Sci., 4th ser., vol. 30, 1912, p. 273.

have been completely covered by the ocean, for remnants of a once continuous sheet of conglomerates, sandstone, and shale are widely distributed in the region.

At the close of Cretaceous time the Klamath Mountains were again uplifted, and with a number of later oscillations and the consequent erosion they have been carved to their present form by streams, which have concentrated the gold in the auriferous gravels.

AURIFEROUS GRAVELS.

LOCATION AND EXTENT OF THE WEAVERVILLE QUADRANGLE.

The Weaverville quadrangle embraces portions of Shasta and Trinity counties, northwestern California, extending from Shasta post office west to the La Grange mine, and from Igo north nearly to Trinity Center. It is a little more than 34 miles in length and 26 miles in breadth, and its area is 905.27 square miles. It is bounded by parallels 40° 30′ and 41° north latitude and meridians 122° 30′ and 123° west longitude.

The Weaverville quadrangle is without railroads, but has good wagon roads connecting it with the main line of the Southern Pacific at Redding, Red Bluff, and Delta. Redding, at a distance of 52 miles from Weaverville, is the main distributing point.

FIELD WORK AND ACKNOWLEDGMENTS.

The principal area of auriferous gravels in the Weaverville quadrangle was roughly outlined on a small scale in 1893[1] and on a larger scale in 1910.[2] The completion of the topographic map of the quadrangle in 1911 has made it possible to map these gravels in greater detail than heretofore. The work was only partly completed in the summer of 1912, and this is merely a brief preliminary report. Mr. H. G. Ferguson and I were associated in the field work and share equally the credit. The map (Pl. I) shows the areal results concerning the auriferous gravels thus far attained.

For information and assistance in the investigation I wish to express my hearty thanks to many mine owners and managers, but chiefly to Messrs. R. C. McDonald, of Trinity Center; J. C. Van Matre, and M. A. Singer, of Minersville; H. L. Lowden, of Weaverville; and Thomas McDonald, of French Gulch.

TOPOGRAPHY AND PHYSIOGRAPHY.

The Weaverville quadrangle has a mountainous topography. Like the rest of the Klamath Mountains, it is part of an uplifted peneplain[3] across which the larger streams have cut broad valleys[4]

[1] Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 414.
[2] Bull. U. S. Geol. Survey No. 470, 1911, p. 16.
[3] Bull. U. S. Geol. Survey No. 196, 1902, p. 15 (Klamath peneplain.)
[4] Idem, p. 49 (earlier valleys).

with even or slightly undulating bottoms so wide as to suggest secondary peneplains [1] and then intrenched themselves in deep canyons [2] with terraced slopes.

The relations of these important physiographic features, recording three cycles of erosion in the Klamath Mountains, are shown in a cross section of the Trinity River valley (fig. 2) a short distance south of Minersville, where the canyon of Trinity River, 1,500 feet in depth, trenches the Sherwood peneplain, well exposed on the long, even spurs of the west slope of Trinity Mountain and the gentle eastward slope of the flat table-land northwest of Buckeye Creek. In the Minersville region the broad divide between Stuart Fork and Rush Creek is called Buckeye Mountain, but as this local usage embraces under the one name features important to be distinguished, I refer herein to the table-land just mentioned as the Buckeye

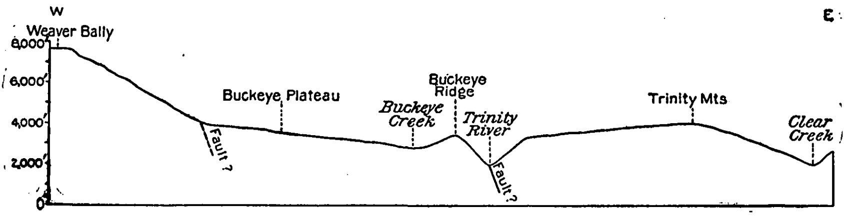


FIGURE 2.—Generalized section across Trinity River valley south of Minersville, Cal., showing the relation of Trinity River canyon to the Sherwood peneplain of Trinity Mountain and Buckeye Plateau and the Klamath peneplain of Weaver Bally.

Plateau and to the prominent ridge southeast of Buckeye Creek and adjoining Trinity River as the Buckeye Ridge.

Although remnants of the Klamath peneplain occur among the Salmon Mountains in the gentle slopes of the crests and peaks at altitudes of about 8,000 feet, they are not prominent in the Weaverville quadrangle. Elsewhere, however, as in the long, even crest of South Fork Mountain and at many other points in the Klamath Mountains, the Klamath peneplain is conspicuous though somewhat lower.

The complex history involved in the development of the physiographic features mentioned will not be discussed in detail in this preliminary report. It is sufficient to say here that all the auriferous gravel in the Klamath Mountains originated in the development of these features.

AREAL DISTRIBUTION OF THE GRAVELS.

On the accompanying map (Pl. I) is shown the areal distribution of the gravels, by solid boundary lines as far as the survey is completed, but by dotted lines where the survey is incomplete.

[1] Bull. U. S. Geol. Survey No. 196, 1902, p. 22 (Sherwood peneplain).

[2] Idem, p. 58 (later valleys); Bull. Dept. Geology Univ. California, vol. 3, No. 22, 1904, p. 425 (Sierran canyons).

The gravels already mapped may be considered as belonging to three areas. The oldest, largest, and most important is that of the Weaverville basin, which is associated with the Sherwood peneplain. This area extends from the La Grange mine to the East Fork of Stuart Fork and may have formerly extended to Trinity Center. Although not now a basin it was at one time and drained directly southwestward to Weaverville and the La Grange mine. The survey of this basin is incomplete. The second area is on Trinity River, extending from Trinity Center to Lewiston. These two areas are in Trinity County and are not subject to restrictions concerning débris. The third area is in Shasta County on Clear Creek, a tributary of the Sacramento, and in it the débris must be controlled.

In the two areas last mentioned the gravels are associated more or less closely in origin with the formation of the stream canyons, and are very much younger than most of the gravels of the Weaverville basin.

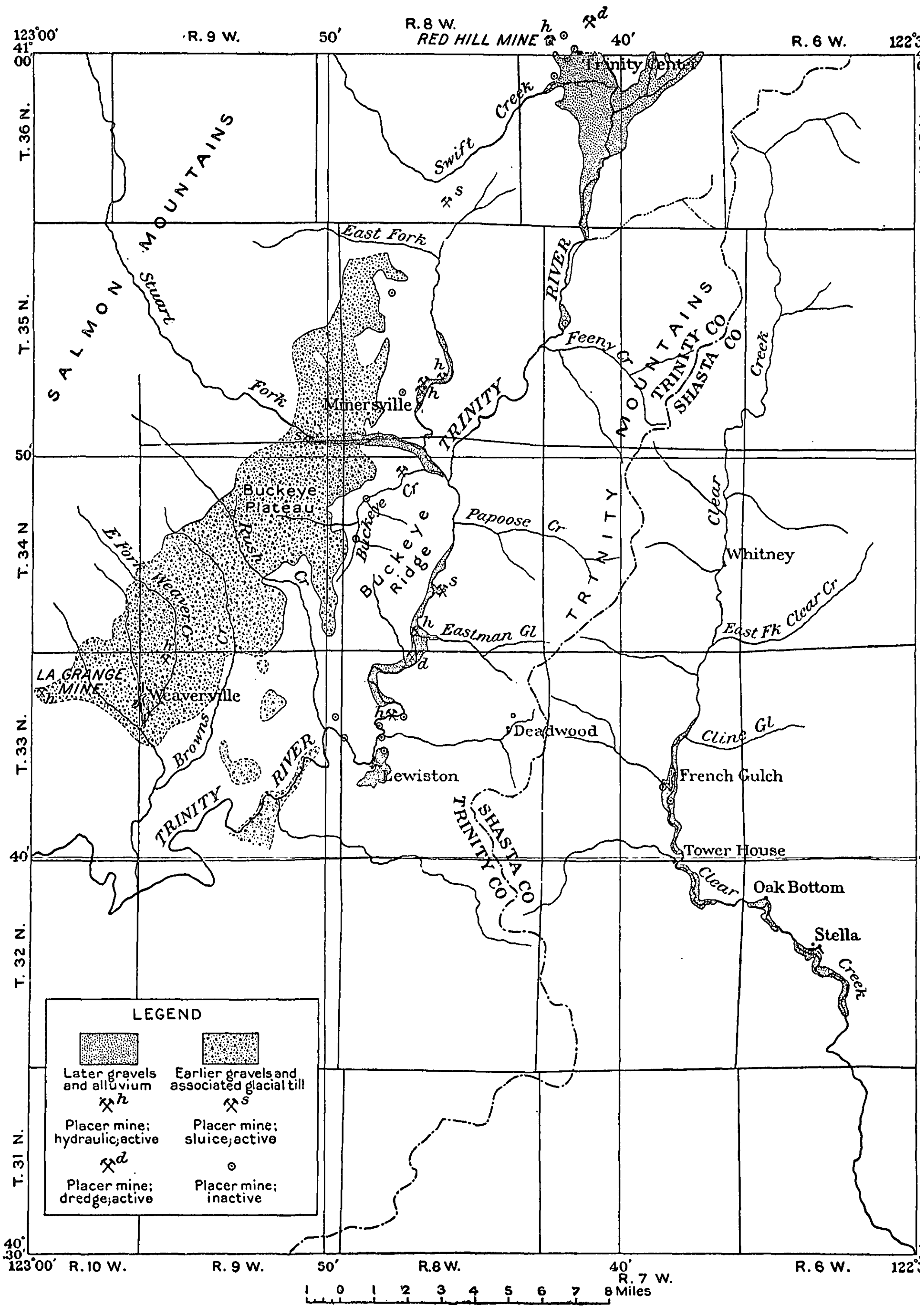
WEAVERVILLE BASIN.

The Weaverville basin area is irregularly triangular, being 24 miles in length if it extends to Trinity Center and 8 miles in greatest width. The base of the triangular area is near Weaverville and the apex at Trinity Center, but there is a wide interruption in the area due to recent glacial action along Swift Creek and East Fork of Stuart Fork. Southeast of Weaverville, in the vicinity of Browns Mountain and Lowden's ranch, there are a number of detached areas which have been included in considering the general form of the mass. Between East Fork of Stuart Fork and Weaverville, a distance of nearly 17 miles, the deposit is continuous, and has a width of 1 to 3 miles.

This large continuous body is not homogeneous. It varies much from place to place and consists of two more or less contrasted classes of material—one including many angular bowlders intermingled with angular to subangular, locally rounded fragments of sand and clay, as in glacial till; the other including for the most part well-rounded fragments, a few bowlders, and gravel commingled with a smaller proportion of sand and clay, as may occur in fluviatile deposits. The relations of these materials can not be discussed to advantage until the survey of the Weaverville basin is completed.

Gravels of the same age as much of the gravel in the Weaverville basin are now worked in the Red Hill mine, 1 mile west of Trinity Center, at an elevation of about 2,800 feet above the sea, or 500 feet above the town. These gravels are very much older than those extensively mined years ago along the western edge of Trinity Center and have been affected by profound earth movements which the later gravels have not experienced.

The gravel of the Red Hill mine is 100 to 125 feet in thickness. Besides being partly cemented it is tilted and faulted down into the



MAP SHOWING AURIFEROUS GRAVELS OF THE MIDDLE AND NORTHERN PORTIONS OF THE WEAVERVILLE QUADRANGLE, CALIFORNIA.

slate bedrock, which belongs to the Bragdon formation. Although 50 per cent of the gravel is less than 2 inches in diameter and the greater part is well rounded, there are, especially near the bottom, a number of bowlders from 3 to 10 feet in diameter. Fine whitish sand, containing large fragments of wood, occurs in places upon the bedrock. Much of the gravel, especially in the upper portion, is completely decomposed and colored pink. The soft pebbles cut like cheese. The lower portion contains pebbles and bowlders of conglomerate from the Bragdon formation, and these are generally hard and smooth.

The gold is moderately coarse, and irregular nuggets worth as much as $30 are sufficiently smoothed by attrition to indicate transportation to a considerable distance.

An area of this gravel at least several acres in extent is still available for mining on the divide between Brush and Hatchet creeks. That on the north slope of Hatchet Creek was mined some years ago. Much of it has been removed by the streams in eroding the present valleys, the gold thus being concentrated and the later gravels at lower levels in the same region enriched.

Between Swift Creek and East Fork small placers have been worked near Davis and Hubbard creeks, branches of the East Fork, about 3 miles north of Bowerman's ranch, but they show very little gravel. Their gold is in residual meta-andesite (greenstone), not far from its contact with the slates of the Bragdon formation.

Northwest of Minersville, between East Fork and Stuart Fork, in the region drained by Strope, Digger, and Mule creeks, a great body of fragmental material forms some of the prominent flat-topped divides that belong to the Sherwood peneplain. The material is bowldery and somewhat angular, resembling glacial till, and it may be at least in part of glacial origin. The bulk of it near the surface, and especially near the peneplain level, is completely decomposed, and in some places the decomposition products are highly colored. In the region northwest of Minersville the material resembling glacial till is not covered with gravel.

The general absence or scarcity of gold in this supposed glacial till, as shown by D. F. MacDonald,[1] has led many of the miners to call it "dead wash." The streams cut through the dead wash in places and derive gold from the underlying bedrock, which in that region is generally an altered ancient lava, meta-andesite.

The most successful placer mines in the Minersville region have been limited to the later gravels of the stream terraces about 100 feet above East Fork, within 4 miles north of Minersville. These bench gravels, as shown on the map, are entirely distinct from the so-called glacial till or dead wash of the hills farther west. The bedrock is

[1] Bull. U. S. Geol. Survey No. 430, 1910, p. 56.

slate (Bragdon formation) except in part of the Unity mine, near the west line of sec. 27, where the bedrock is meta-andesite. The gravel is generally well washed, contains some bowlders, and has a thickness of 40 to 100 feet, forming a terrace much of which yet remains to be mined. The water for the mine, which is now said to be under the control of the Trinity Gold & Hydraulic Dredging Co., is to be supplied from East Fork by a 12-mile ditch carrying 3,000 miner's inches to a 300-foot head.

Between Stuart Fork and Rush Creek there is a great body of fragmental deposits made up in part of more or less angular material that suggests glacial origin but including much gravel that is well rounded by water. The main belt crossing the Buckeye Plateau lies west of Buckeye Creek. It has a width apparently of nearly 3 miles and a depth where greatest of more than 800 feet. Three shafts from 40 to 195 feet in depth have been sunk on the top portion of this deposit to test it for gold. Little if any gold is said to have been found and no actual mining tests resulted.

The surface of the Buckeye Plateau is generally reddish soil to a depth of 15 feet or more, passing downward into a sandy argillaceous mass in which the forms of rounded to subangular fragments and some bowlders may be seen and a few well-rounded solid pebbles are preserved. On the plateau surface there are for the most part only a few scattered pebbles with here and there a small well-rounded bowlder, but on the slopes of the ravines cut by branches of Buckeye Creek, as well as on the plateau borders facing Rush Creek and Stuarts Fork, well-rounded gravel is in many places abundant and extensive. Buckeye Creek drains the great body of fragmental material that forms the Buckeye Plateau. The main portion of the creek was rich in placer gold, but it received its gold chiefly from the east side, where Dutch and Whitney gulches, draining contacts of slate and porphyry, were very much richer than the gulches on the west, heading in the plateau.

Rush Creek, whose present stream bed affords some good placers, cuts a deep, narrow valley directly across the old channel but does not reach the bottom.

The greater portion of the gravels of Weaverville basin lies southwest of Rush Creek, forming the divide between Rush and Browns creeks on one side and the branches of Weaver Creek on the other. In the vicinity of Weaverville the older gravels were in large measure worked over by modern streams and the gold was concentrated in the later gravels, which are rich and have been mined for many years.[1] The gold of the later gravels is derived chiefly from the older gravels, but the older gravels are in few places, if anywhere, so rich as to afford profitable placer ground. This fact explains why the immediate

[1] The inactive mines in that region are so numerous that no attempt has been made to map them.

vicinity of Weaverville has been almost completely washed in placers, while the gravel divides are as yet untouched.

The lower portion of the deposits in the Weaverville basin is generally much finer and more firmly cemented than the upper portion. In the mine formerly known as the Hupp mine it is conveniently used as bedrock for working the upper portion as a placer.

The La Grange mine and that of the Trinity River Consolidated Hydraulic Mining Co. (formerly the Hupp mine) are the most important placers in the Weaverville basin. Both of them have been noticed in earlier publications[1] of the Survey, and need only be referred to in this report.

TRINITY RIVER AREA.

The Trinity River area, so far as already mapped, includes the gravels from Trinity Center to Lewiston. All the gravel of this area belongs to the later portion of the canyon-cutting epoch. The gravels of this epoch may be conveniently referred to as later gravels, in comparison with the earlier gravels of the Weaverville basin area. The Red Hill mine, at the edge of this area, belongs geologically in the Weaverville basin and has been described on pages 10–11.

In the vicinity of Trinity Center, which has been a great placer camp for many years, the stream beds are deeply aggraded. On one side the gravels merge into the glacial material of Swift Creek and on the other they are covered by the alluvium of the present streams. On the western border of Trinity Center an old river terrace, once nearly half a mile in length, has been mined away, leaving a gravel bluff in places over 100 feet in height. Above this bluff there are remnants of gravel at intervals on the slope leading up to the Red Hill mine, in which occur the earlier gravels belonging to the same formation as those of the Weaverville basin area, described on page 10.

A short distance north of Trinity Center, on a broad gravel flat near Trinity River, a bucket dredge has been successfully operated more or less continuously since 1903. Dredging was suspended in the summer of 1912 to install a chain of 61 new $7\frac{1}{2}$-foot buckets and otherwise improve the machinery. Considerable ground has already been covered, and there is enough ahead to keep the dredge at work for several years. The success of this project has led to prospecting at other points in the vicinity, especially in the wide alluvial expanse within several miles south of Trinity Center, but as yet, so far as I am aware, no new dredging operations have been commenced.

Along Trinity River for more than 20 miles south of Trinity Center there has been very little placer mining; but at Mooney Gulch begins a region of greater activity. There is a placer mine on Mooney

[1] Bull. U. S. Geol. Survey No. 430, 1910, pp. 51–56; No. 470, 1911, pp. 16–18.

Gulch a quarter of a mile above its mouth and a hydraulic mine on the river at the mouth of Eastman Gulch. Both have been productive for some years.

Recently two new projects have been opened in that region with unusually extensive preparation. These are the dredge of the Trinity River Dredging Co. and the hydraulic mine of the Trinity River Mining Co.

The Trinity River Dredging Co. has erected an electric dredge on a gravel flat of Trinity River at the mouth of Jennings Gulch, about 4 miles above Lewiston. The dredge is said to have a chain of forty-four 11-foot buckets that can reach a depth of 40 feet. The powerhouse is 5 miles farther up Trinity River, near the mouth of Stuart Fork. The water is brought from Stuart Fork by a ditch 7½ miles in length and delivered at the powerhouse with a head of 285 feet. In September, 1912, with the power plant already running and the dredge nearly completed, the company was about to begin operations. There is a large amount of available ground along Trinity River below this point, and many of the people of that region are greatly interested in the success of this dredge.

A few years ago the Trinity River Mining Co. attempted to drain the bed of Trinity River at Big Bend, a mile north of Lewiston. A tunnel 1,385 feet in length was constructed, giving a head of 25 feet, which was utilized in a turbine and centrifugal pump to force water directly into pipes for hydraulic mining. The tunnel did not completely drain the river, but the available water power was used for hydraulicking some of the gravels in the vicinity. This property has been leased by the Horseshoe Placer Mining Co., which proposes to construct a concrete dam at the intake of the tunnel to complete the drainage of nearly a mile of the river bed.

The gravel of Trinity River for some distance above Lewiston has been aggraded in places to a depth of 30 feet and affords an opportunity for successful mining beneath the river. Near the mouth of Deadwood Gulch two shafts were sunk by the side of the river to a depth of 30 feet, passing through 17 feet of cement underlain by 8 feet of gravel. The gravel was mined out beneath the river for a distance of 267 feet.

CLEAR CREEK AREA.

The bed of Clear Creek from French Gulch to and beyond Stella, in Shasta County, was washed in many places years ago. At several points, especially in the vicinity of French Gulch, the mining included the terraces up to 100 feet. In like manner the beds of Whiskey Creek and other tributaries of Clear Creek were for the most part mined long since, so that comparatively little ground is available at the present time. Only two placer mines were reported in Shasta

County in 1911. Both were in the vicinity of French Gulch and used ground sluicing.

On Clear Creek, as on Trinity River, much of the gold now found in the gravels is derived from the residual material at the contacts between the slates (Bragdon formation) and the more ancient lavas, or the porphyry dikes. In many places these contacts may be well worth washing as placers.

OUTLOOK FOR PLACER MINING IN THE DISTRICT.

The outlook for future placer mining in this region is encouraging. The success of the La Grange mine consists in the economical treatment on a large scale of relatively low grade gravel. The great body of fragmental material to which that of the La Grange mine belongs extends northeastward from the La Grange mine to and beyond Stuart Fork, and may include other bodies of gravel similar to that of the La Grange mine. It lies parallel to and beneath the great ditch that supplies water to the La Grange mine, and any other masses of gravel in the same belt could therefore be easily tested on an appropriate scale. The streams within the Weaverville basin, though partly aggraded, would generally afford a fair dumping ground for the higher gravel, and where the gravel is not too firmly cemented it might, with facilities equal to those of the La Grange, be economically mined.

The success of the dredging at Trinity Center and of the placers north of Lewiston gives confidence to those who are attempting larger developments at the mouth of Eastman Gulch and at the bend of Trinity River above Lewiston, and the region may well be regarded as worthy of investigation by capitalists interested in dredging and hydraulic mining.

GOLD LODES OF THE WEAVERVILLE QUADRANGLE, CALIFORNIA.

By Henry G. Ferguson.

SITUATION AND AREA.

The Weaverville quadrangle includes parts of Trinity and Shasta counties, Cal., and at its northwest corner touches the southern point of Siskiyou County. It lies between 40° 30′ and 41° north latitude and 122° 30′ and 123° west longitude, and covers an area of 905.27 square miles. The country is mountainous and sparsely populated. A few small mining camps such as Minersville, Trinity Center, French Gulch, and Whiskeytown were prosperous towns in the early days of the rich placer workings. Along the valley of Trinity River there is a small amount of farming land. The principal town is Weaverville, the county seat of Trinity County, with a population of 913. The city of Redding, on the Southern Pacific Railroad in Shasta County, serves as a distributing point for the entire quadrangle, except the extreme northeast corner. Daily stages run from Weaverville to Redding, a distance of 54 miles, and from Trinity Center to Delta.

The extreme southern and western portions of the quadrangle, including the Igo district, in Shasta County, the Bully Choop and Eastman Gulch districts, in Trinity County, and the Keswick (Iron Mountain) copper district already described by Graton,[1] are not covered by this report.

FIELD WORK AND PREVIOUS DESCRIPTIONS.

The writer had the opportunity of visiting the principal gold mines in the course of the areal geologic mapping of the quadrangle during the field season of 1912 as assistant to J. S. Diller. He is greatly indebted to Mr. Diller for criticism and suggestions and to all the mining men of the region for courtesy and hospitality.

[1] Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 71.

Very little has been written bearing directly upon the lode deposits of the region. The geology, physiography, and placer deposits have been discussed in papers by Diller,[1] Hershey,[2] and MacDonald.[3]

The area immediately to the east has been mapped and described by Diller [4] and the copper deposits of the Shasta copper belt by Graton.[5] The lode deposits of certain districts north of the Weaverville quadrangle have been described by Hershey [6] and MacDonald.[7] Hershey [8] has also discussed the origin of the pocket deposits which form a feature of part of this area.

GEOGRAPHY.

The Weaverville quadrangle lies entirely within the topographic province of the Klamath Mountains. Two streams, Clear Creek and Trinity River, with their tributaries, drain almost the whole area. Clear Creek rises in the extreme northeast corner and flows in a general southerly direction, leaving the quadrangle near Igo, in the southeast corner. This point is the lowest in the area, having an elevation of less than 800 feet above sea level. Clear Creek empties into Sacramento River 5 miles south of Redding. Trinity River enters the quadrangle from the north at Trinity Center and flows in a general southwesterly direction. It leaves the area at a point 5 miles southwest of Weaverville and flows northwestward for 60 miles to Klamath River. The divide between these two streams is the boundary between Trinity and Shasta counties. Two groups of mountains are conspicuous features of the topography. The Salmon Mountains, cut in two by Stuart Fork, reach a maximum elevation of 8,879 feet in an unnamed peak in the extreme northwest corner of the area. Along the southern border of the quadrangle are the

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[1] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 397–434; Revolution in the topography of the Pacific coast since the auriferous-gravel period: Jour. Geology, vol. 2, 1894, p. 32; Topographic development of the Klamath Mountains: Bull. U. S. Geol. Survey No. 196, 1902; Klamath Mountain section, California: Am. Jour. Sci., 4th ser., vol. 15, 1903, pp. 342–362; The Bragdon formation: idem, vol. 19, 1905, pp. 379–387; The auriferous gravels of the Trinity River basin, California: Bull. U. S. Geol. Survey No. 470, 1911, pp. 11–29. See also Auriferous gravels in the Weaverville quadrangle, in this volume, pp. 5–15.

[2] Hershey, O. H., Metamorphic formations of northwestern California: Am. Geologist, vol. 27, 1901, pp. 225–245; Some evidence of two glacial stages in the Klamath Mountains in California: idem, vol. 31, 1903, pp. 139–156; Structure of the southern portion of the Klamath Mountains, California: idem, pp. 231–245; Sierran valleys of the Klamath region: Jour. Geology, vol. 11, 1903, pp. 155–165; The Bragdon formation in northwestern California: Am. Geologist, vol. 33, 1904, pp. 248–256; The river terraces of the Orleans basin, California: Bull. Dept. Geology Univ. California, vol. 3, 1904, pp. 423–475.

[3] MacDonald, D. F., The Weaverville-Trinity Center gold gravels, Trinity County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 50.

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

[5] Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 71.

[6] Hershey, O. H., Gold-bearing lodes in California: Am. Geologist, vol. 25, 1900, pp. 76–96.

[7] MacDonald, D. F., Notes on the gold lodes of the Carrville district, Trinity County, Cal.: Bull. U. S. Geol. Survey No. 530, 1913, pp. 9–41.

[8] Hershey, O. H., Origin and age of certain gold deposits in northern California: Am. Geologist, vol. 24, 1899, pp. 38–43; Origin of gold pockets in northern California: Min. and Sci. Press, vol. 101, 1910, pp. 741–742.

Bully Choop Mountains, whose highest point, Bully Choop, has an elevation of 6,964 feet.

The greater part of the area consists of irregular sprawling ridges, brush covered or timbered, whose summits are remnants of a deeply dissected peneplain and which attain a maximum elevation of slightly over 5,000 feet along the northern border and grade down to about 3,500 feet near Whiskeytown. Along the eastern border of the quadrangle this upland falls off sharply into the north end of the broad Sacramento Valley.

GEOLOGY.

BROAD FEATURES.

The geologic history of the Klamath Mountains, of which the Weaverville quadrangle is a part, is summarized in the paper by J. S. Diller on pages 13–14, and hence a description of the rock formations will be sufficient for the purposes of the present paper. In the western part of the area are found older biotite and hornblende schists, the former containing lenses of crystalline limestone. In the eastern and central parts the Copley meta-andesite (Devonian or older)[1] is overlain unconformably by the Bragdon formation (Mississippian). Later movements which have affected these have left their mark in the irregular line of contact of these two formations and in the contortion of the Bragdon formation. In late Jurassic or early Cretaceous time[2] came a period of igneous activity producing the complicated series of granitic and porphyritic rocks which to-day occupy a large proportion of the surface. During Cretaceous and Tertiary time the region passed through several stages of erosion and base-leveling.

The accompanying geologic map (Pl. II) was made during the field season of 1912 by Mr. Diller and the writer and shows the principal rock formations of the area covered by the season's field work and the location of the more important lode mines.

SEDIMENTARY ROCKS.

The oldest sedimentary rock of the quadrangle is a biotite schist, a portion of the Salmon schist of Hershey,[3] a small mass of which outcrops between the serpentine and quartz diorite at the head of the East Fork of Trinity River. The schist contains some lenses of limestone that have been completely recrystallized by the intrusion of the quartz diorite, with the development of much garnet and epidote.

Except for the schist the pre-Carboniferous rocks of the quadrangle are represented only by the hornblende schist and meta-

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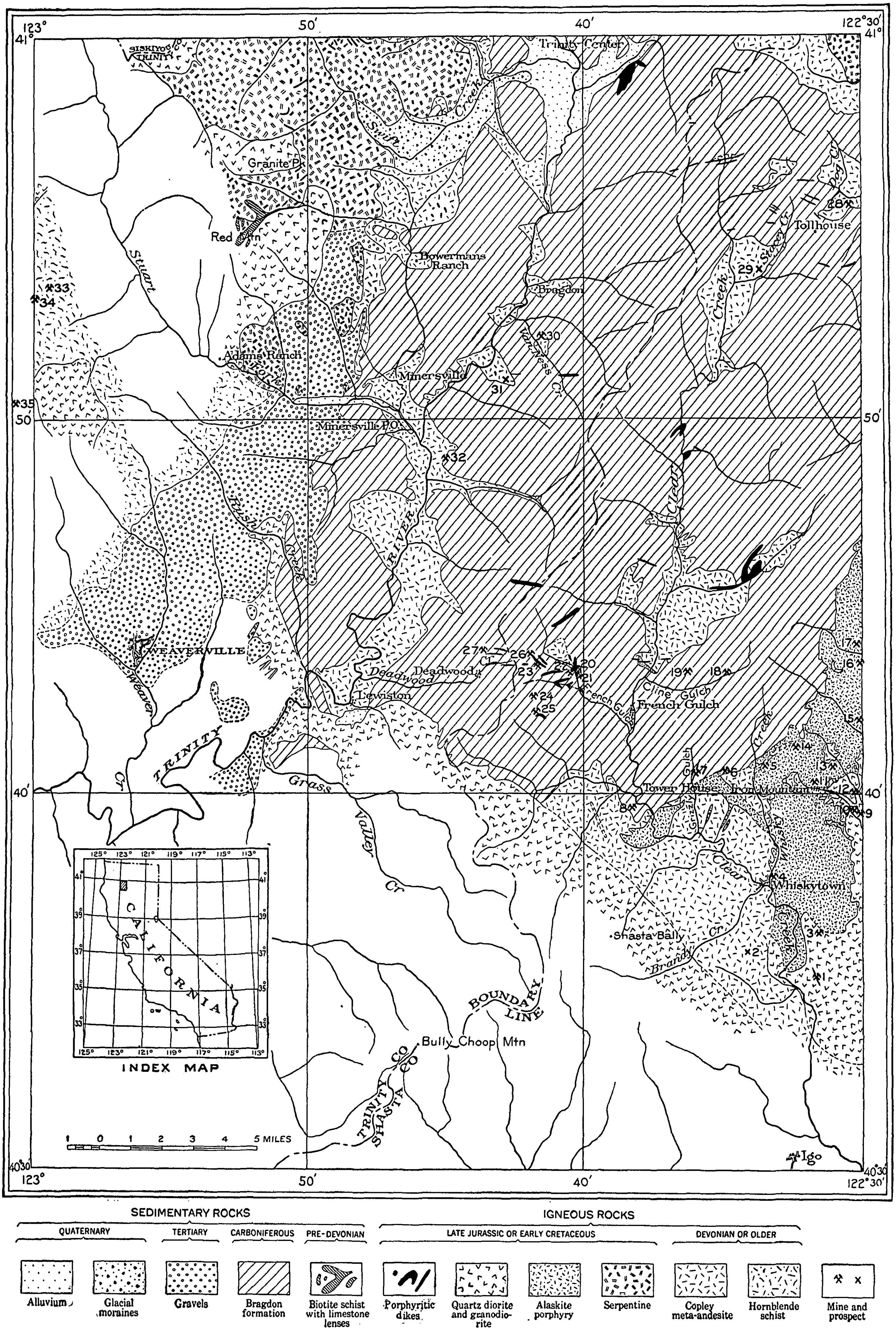
[1] Diller, J. S., Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 6.

[2] Idem, p. 10.

[3] Hershey, O. H., Am. Geologist, vol. 27, 1901, p. 225.

MINES AND PROSPECTS

1. Mt. Shasta
2. Mountain Monarch
3. Mascot
4. Gambrinus
5. Mad Ox
6. Mad Mule
7. Truscott
8. El Dorado
9. Minnesota
10. Hidden Treasure
11. Iron Mountain
12. Little Nelly
13. Hornet
14. Lone Star
15. Hardtack
16. Balaklala
17. Great Verde
18. Gladstone
19. American
20. Franklin
21. Milkmaid
22. Washington
23. Niagara
24. Summit
25. Brunswick
26. Accident
27. Brown Bear
28. Delta
29. Stacey
30. Five Pines
31. Mountain View
32. Fairview
33. Globe
34. Bailey
35. Craig



GEOLOGIC MAP OF PART OF THE WEAVERVILLE QUADRANGLE, CALIFORNIA.

andesite described below under "Igneous rocks." In the neighboring Redding quadrangle[1] the Devonian shale and limestone (Kennett formation) are important fossiliferous strata, but they do not extend into this area. Pebbles of fossiliferous Devonian limestone are, however, found in the conglomerates of the overlying Bragdon formation.

The Bragdon formation[2] consists of conglomerates, sandstones, and carbonaceous slates, the slates greatly predominating. The Bragdon rests upon the meta-andesite, but there is evidence of motion almost everywhere along the contact, and only in a few places is anything in the nature of a basal conglomerate to be seen. Here and there a feldspathic sandstone forms the base of the Bragdon. Conglomerates are found in lenticular layers distributed irregularly throughout the formation. These are in places coarse and badly assorted and comprise subangular as well as rounded pebbles. The pebbles consist chiefly of slate, chert, and quartz, with locally numerous limestone pebbles, some of which are fossiliferous, and rarely pebbles of meta-andesite. The sandstone of the Bragdon is for the most part fine grained. It is dark from the presence of carbonaceous matter and is everywhere more or less feldspathic. Faint cross-bedding is occasionally seen. The shales constitute the major part of the formation and are fine grained and in places extremely carbonaceous. They are locally interbedded with sandstone in thin layers, but more commonly there is a considerable thickness of shale beds, uninterrupted by sandstone or conglomerate. Beds of tuff are of rare occurrence. The total thickness of the Bragdon, as estimated by Diller[3] in the Redding quadrangle, is between 2,900 and 6,000 feet. The shale contains numerous fragmentary plant remains. Fossils (chiefly crinoids) which indicate a Carboniferous age have been found by Diller in the conglomerates, sandstones, and tuffs.

Along the contact of the Bragdon with the granodiorite, particularly in the vicinity of Lewiston, contact metamorphism has developed a series of highly altered rocks, including quartzite and various types of amphibole and mica schists.

None of the Carboniferous formations which in the Redding quadrangle overlie the Bragdon formation extend as far west as this area, nor do the Triassic, Jurassic, and Cretaceous sediments of the Redding region enter the surveyed portion of the Weaverville quadrangle. Tertiary gravels cover a triangular strip west of Trinity River and extend from Trinity Center to the Weaverville basin, and more recent bench gravels follow the present stream courses.

[1] Diller, J. S., Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 2.

[2] Hershey, O. H., Am. Geologist, vol. 27, 1901, p. 238; vol. 33, 1904, pp. 248-256. Diller, J. S., Am. Jour. Sci., 4th ser., vol. 19, 1905, pp. 379-387.

[3] Diller J. S., Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 3

The gravels have been studied in detail by Diller.[1] Local glaciation has carved out cirques and glacial valleys in the Salmon Mountains, and morainal material is found as far into the lowlands as the lower part of Swift Creek.

IGNEOUS ROCKS.

COPLEY META-ANDESITE.

One of the oldest rocks of the area is the meta-andesite, of Devonian age or older,[2] which covers a triangular area of about 6 by 8 miles west of Whiskeytown, and which has been exposed by the erosion of the Bragdon formation in several smaller patches along Clear Creek and Trinity River.

For the most part the formation consists of a series of vesicular lava flows, with minor amounts of tuff and breccia, everywhere much altered. Commonly the rock has a rusty outcrop and a green color on fresh fracture. Intense shearing is the rule, giving a greasy appearance, and it is rare that individual minerals can be distinguished. Where the rock is spherulitic its appearance is extremely characteristic, as small spheres of quartz and epidote 2 or 3 millimeters in diameter are closely crowded together. The breccias are most noticeable on their weathered surfaces, owing to difference in weathering between the rock fragments, which are bleached, and the matrix, which remains a dull green.

In the typical meta-andesite pyroxene was originally the most prominent mineral, but it is now almost completely altered, usually to chlorite and epidote with a little calcite, more rarely to hornblende. Plagioclase feldspar is present in varying amounts, both in phenocrysts and in the groundmass but is likewise much altered. In many places the rock is composed largely of secondary minerals, chiefly chlorite, epidote, and calcite.

Regional metamorphism has affected the meta-andesite to an extent which makes it impossible to distinguish the individual flows. The spherulitic and breccia phases are most abundant in the region north of Whiskeytown. A specimen from an outcrop of extremely spherulitic lava shows microscopic grains of quartz, apparently original, and hence should be classed as a dacite or rhyolite. Fragments of quartz-bearing lava were also found in one of the breccias. With these exceptions these early lavas seem to be pyroxene andesite.

[1] Diller, J. S., The auriferous gravels of the Trinity River basin, California: Bull. U. S. Geol. Survey No. 470, 1911, pp. 11–29.

[2] Diller, J. S., Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 6.

HORNBLENDE SCHIST.

The rock here described as hornblende schist, a part of the Salmon schist of Hershey,[1] outcrops in the western part of the area from near Weaverville north to beyond the Globe mine. The rock varies greatly in texture and composition. In the Rush Creek region it is extremely fine grained and the numerous minute hornblende needles give it a silky sheen. In places the texture is so fine that the individual crystals can not be distinguished with a lens. Here and there are minute biotite plates (under 2 millimeters in diameter) Under the microscope hornblende is seen to compose from 70 to 90 per cent of the rock. In places it shows partial alteration to serpentine and chlorite, and the biotite, where present, is chloritized. Small grains of epidote are locally present in association with the hornblende. A little quartz is always present, either as small lenses parallel to the schistosity or in poorly defined bands with the hornblende. With the quartz is associated in places a little lime-soda feldspar in small irregular grains. Magnetite and ilmenite are common accessories.

The coarse-grained type of rock is particularly prominent in the vicinity of the Globe mine. Here the hornblende is in crystals large enough to be readily identified by the eye and the rock is diversified by small bands and lenses of quartz and feldspar.

The hornblende schist is distinctly older than the other intrusive rocks of the quadrangle, but no data could be obtained as to its age relative to the meta-andesite.

INTRUSIVE ROCKS.

TYPES AND COMPOSITION.

Approximately half the surface of the quadrangle is occupied by intrusive rocks of various types, including serpentinized peridotite and saxonite, quartz diorite, granodiorite, and several types of porphyries and lamprophyres. The accompanying table illustrates the difference in mineral content of the different varieties. Their relations, for the most part, have not yet been determined with sufficient certainty to allow any definite statement as to their relative age. All are intrusive into the Bragdon formation and belong presumably to the same general period of igneous activity. Diller[2] places the age of the quartz diorite batholith in the Redding quadrangle as late Jurassic or early Cretaceous.

[1] Hershey, O. H., Am. Geologist, vol. 27, 1901, pp. 225-245.
[2] Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 8.

Mineral composition of the intrusive rocks of the Weaverville quadrangle.

[0, Lacking; 1, rare or accessory; 2, present in small amount; 3, common; 4, prominent; 5, comprises greater part of the rock.]

Name.	Quartz.	Orthoclase.	Albite.	Soda-lime feldspar.	Biotite.	Hornblende.	Augite.	Monoclinic pyroxene.	Olivine.	Distribution.
Peridotite	0	0	0	0	0	0	0	0–2	5	In northeast and northwest corners. Parts of larger areas.
Saxonite	0	0	0	0	0	0	0	3–4	4	In northwestern portion.
Quartz diorite	2–3	0–1	0–1	4	0–2	3	0	0	0	Chiefly in southeastern portion. Part of large batholith.
Granodiorite	3	2	0–1	3–4	3	0–2	0	0	0	Chiefly in southern and western parts. Blends into granodiorite.
Alaskite porphyry	3–4	0–1	4	0	0–1	0	0	0	0	Large area in southeastern portion.
Soda granite porphyry	3	0–1	4	0–1	3–4	0	0	0	0	Numerous dikes and small masses. Cuts the alaskite porphyry.
Diorite porphyry	0–1	0	0–1	4	0–2	0–3	0–2	0	0	Cuts Bragdon formation in small dikes.
Dacite porphyry	4	0	0	4	3	2	0	0	0	Found only in two dikes, cutting the Bragdon formation.
Quartz-augite diorite	1–2	0	0	3	1	0	4	0	0	Dikes, chiefly cutting the quartz diorite.
Lamprophyre (spessartite type).	1	0–1	0	2	2	4–5	1	0	0	Small dikes, comparatively rare.
Lamprophyre (hornblende picrite).	0	0	0	0	0	5	1	0	0	Single dike only.

SERPENTINE.

West of Trinity River a belt of serpentinized basic rock extends for about 8 miles along the northern border of the quadrangle, and reaches southward for about 4 miles. A second and much smaller area lies at the extreme northeast corner of the quadrangle. Both are extensions of larger areas to the north. Chromite has been mined in the serpentine area to the northeast, but none has been found within the quadrangle and no gold deposits occur within the region covered by the serpentine.

The rock of the northeastern area is a peridotite containing everywhere a minor amount of pyroxene. It has a rusty-brown color and a minute lattice-like surface texture on its outcrop but is dark gray, nearly black, on fresh fractures. The cleavage faces of the few pyroxene crystals can be readily distinguished. Pyroxene, largely serpentinized, may form as much as 20 per cent of the volume of the rock. The remainder is composed of olivine, in part altered to serpentine and secondary magnetite.

In the larger area in the northwest corner of the quadrangle much of the rock contains a variable but larger amount of pyroxene (enstatite), so that it is generally a saxonite rather than a peridotite. The alteration product of the pyroxene is more resistant to weathering than the meshlike serpentine formed from the olivine, and hence the weathered surface is very rough and irregular, the pyroxene grains standing out in relief. All the sections examined microscopically are more or less serpentinized, and even in the pyroxene-rich rocks the olivine is somewhat in excess of the pyroxene. Other specimens consist entirely of olivine and its alteration products. The peridotite and saxonite, however, are so intimately mixed that it was not possible to separate them in the field.

QUARTZ DIORITE AND GRANODIORITE.

The southern and western portions of the quadrangle are to a large extent occupied by great masses of granitic rock, parts of a great batholith which underlies a large portion of the Klamath Mountains. A small area south of Whiskeytown is an extension from the larger mass mapped by Diller[1] in the Redding quadrangle. To the west of this area, separated only by a narrow strip of meta-andesite cover, is the rock which forms the mass of Shasta Bally, and farther northwest are isolated patches in the Salmon Mountains. In the lowlands the rock is deeply weathered, owing to the decomposition of the dark silicates, and in places is reduced to a quartz and feldspar sand. On the steeper slopes, as on Shasta Bally and on the flanks of Red Mountain, where erosion is rapid, the less weathered portions of the rock stand out as great monoliths. In the more rugged canyons and glaciated portions of the Salmon Mountains fresh granodiorite forms prominent cliffs, whose faces follow the steeply inclined joint planes.

The rock exhibits a considerable variety in both textural and mineralogic characteristics. Its most usual type is a medium-grained (2 to 4 millimeters) granular rock carrying quartz, plagioclase feldspar, little or no orthoclase, and both biotite and hornblende. As a rule it is even grained, but in places, as along the toll road east of Whiskeytown, it is distinctly porphyritic, with large corroded phenocrysts of quartz. Aplitic dikes are not uncommon, and many hornblendic streaks (schlieren) and irregular segregations rich in hornblende are found near the borders of the mass.

The ferromagnesian minerals, hornblende and biotite, vary greatly in their relative proportions; in certain parts of the area biotite is dominant and hornblende is present in minor amount or completely lacking, while elsewhere hornblende is the only essential dark silicate present. The greater part of the feldspar individuals are plagioclase and many of them show a zonal structure. The usual composition is oligoclase or oligoclase-andesine with a center of andesine. A large proportion of the feldspars are untwinned and in some of the slides examined these are in part orthoclase. Although no thorough study of the feldspars has been made it is believed that even where orthoclase is most abundant it rarely exceeds 10 per cent of the rock. Orthoclase appears to be most abundant where biotite is the dominant ferromagnesian mineral. Quartz is present in small anhedral grains except in the porphyritic phase already referred to, where it occurs

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

also as corroded phenocrysts a centimeter or more in diameter. Accessory minerals are inconspicuous. They include apatite, magnetite, ilmenite, zircon, and, in one specimen, garnet.

ALASKITE PORPHYRY.

Alaskite porphyry[1] is a rock of great economic importance in the extreme eastern part of the quadrangle and in the region to the east, as it forms the wall rock of the Shasta County copper deposits. In the Redding quadrangle it covers a large area. In the Weaverville quadrangle it lies along the eastern border in an irregular north-south band some 13 miles in length and about 3 miles wide. In its northern portion it was intruded between the Bragdon formation and the Copley meta-andesite and in the south it separates the quartz diorite and the meta-andesite. A small discrete area lies to the south of Tower House, and dikes were encountered on Clear Creek north of Cline Gulch and on Van Ness Creek southeast of the Five Pines mine.

The rock varies greatly in texture. A coarse-grained porphyritic type that outcrops along the eastern boundary of the area closely resembles the porphyritic quartz diorite, into which it grades. The finer-grained type is more usual and is particularly well exposed in the region north and northeast of Whiskeytown. It is white or light green in color, gray in the freshest specimens, and where pyritized is heavily iron stained on the outcrop. In outward appearance it resembles a rhyolite, as it has a distinctly platy fracture, due to later shearing, and shows minute crystals of quartz and more rarely of feldspar in a dense aphanitic groundmass.

The distinguishing feature of the mineral composition of the alaskite porphyry is the absence of ferromagnesian minerals. Even in the freshest specimens, microscopic examination showed no dark silicates except small specks of chlorite, which possibly represent altered biotite, and minute grains of epidote and zoisite, which may likewise indicate the original presence of a small amount of ferromagnesian minerals. The feldspar, both the phenocrysts and microlites in the groundmass, is albite. The groundmass, even of the most aphanitic type, is holocrystalline and consists of an aggregate of minute grains of quartz and rods of feldspar.

SODA GRANITE PORPHYRY.

Soda granite porphyry is closely allied to the alaskite porphyry in mineral composition. Dikes of this rock have been noted by Butler[2] cutting the alaskite porphyry in the Iron Mountain district. Similar

[1] Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 81.

[2] Butler, B. S., Pyrogenetic epidote: Am. Jour. Sci., 4th ser., vol. 28, 1909, p. 27.

dikes are common throughout the Bragdon formation and appear to have a rather close association with the fissure veins in that formation. The rock is always porphyritic but varies greatly in texture in different localities. Most commonly the phenocrysts are about equal in volume to the groundmass, and the groundmass, though in places extremely fine grained, is everywhere distinctly crystalline. The phenocrysts named in the usual order of their abundance are biotite, feldspar, and quartz. Biotite occurs generally in thin hexagonal plates commonly not over 2 or 3 millimeters in diameter. The feldspar phenocrysts are euhedral but generally very small, few of them exceeding 3 millimeters in length. Most of the determinable feldspars proved to be nearly pure albite. In a few dikes, however, the prevailing feldspar is oligoclase, and more rarely a little orthoclase is present. Quartz crystals are generally less prominent than biotite and feldspar, but the relative amount varies greatly in the different dikes. Few of the phenocrysts show good crystal outlines, and deep embayments due to magmatic corrosion are a characteristic feature. The accessory minerals are titanite, zircon, magnetite, and rarely colorless garnet and epidote.[1] The groundmass is always holocrystalline but in most places extremely fine grained; it consists of quartz and feldspar with scattered grains of the accessory minerals. The feldspar of the groundmass, in most of the slides examined, seems to have the same composition as the feldspar phenocrysts.

DIORITE PORPHYRY.

Diorite porphyry, locally known as "bird's-eye porphyry," forms prominent dikes in the Bragdon formation, particularly in the French Gulch and Whiskeytown region. The noticeable feature of the rock is the presence of numerous white feldspar phenocrysts, some of them as much as a centimeter in length, in a dark-gray groundmass. The composition of all the feldspars was not determinable, but in general they vary between albite-oligoclase and calcic andesine, the latter being the most common. Hornblende is the most abundant ferromagnesian mineral and may generally be seen in the hand specimen as small needles 1 or 2 millimeters long. Augite or biotite may be present as well as hornblende, but neither is common and augite is the rarer of the two. In one dike, however, augite is the only dark silicate present and exceeds the feldspar phenocrysts in volume. Small biotite plates are more common, and in a dike near the Washington mine biotite is the only ferromagnesian mineral present. The groundmass is extremely fine grained and consists of very minute feldspar laths with rare specks of hornblende and biotite.

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[1] Butler, B. S., Pyrogenetic epidote: Am. Jour. Sci., 4th ser., vol. 28, 1909, p. 27.

DACITE PORPHYRY.

Dikes of dacite porphyry cut the Bragdon formation at Smiths Gulch, 4 miles north of French Gulch, and on the East Fork of Clear Creek. Specimens from the dike at Smiths Gulch have been included in the educational series of rock specimens of the Geological Survey and have been described in detail by J. P. Iddings.[1] The prominent feature of the rock is the presence of large rounded quartz phenocrysts, the largest nearly a centimeter in diameter. Phenocrysts of milky-white oligoclase feldspar are more numerous than those of quartz. Small biotite and hornblende crystals are also common.

Rock of this type forms several dikes in the Redding quadrangle and appears to correspond to the granodiorite porphyry of the Headlight mine, north of Trinity Center, described by D. F. MacDonald.[2]

QUARTZ-AUGITE DIORITE.

Dikes of quartz-augite diorite occur in the granite area south of Whiskeytown, near the Mount Shasta, Mascot, and Gambrinus mines, and on Clear Creek 9 miles north of French Gulch. There is a large intrusion of a rock of similar composition in the central part of the Redding quadrangle.[3] The rock also appears to be essentially like the basaltic dikes which MacDonald [4] considers to be genetically connected with many of the ore deposits of the region immediately north of the Weaverville quadrangle.

The rock is dark colored, as the dark silicates exceed in amount the quartz and feldspar. Wherever seen it is of granular texture, the grains being about 1 millimeter in size. Augite is the dominant mineral but is largely chloritized. It is possible that a little biotite was also originally present. The feldspar is much altered, but wherever determinable proved to be andesine. Original quartz occurs in small amount and is interstitial between the augite and feldspar.

LAMPROPHYRIC DIKES.

A wide variety of basic dikes has been found in the quadrangle, particularly along the borders of the granodiorite masses. They are small and inconspicuous and as a rule do not exceed a few feet in width. Hornblende is the most prominent mineral in both the phenocrysts and the groundmass and may form as much as 70 per cent of the volume of the rock. Biotite is the second ferromagnesian mineral in abundance, though always far less in amount than hornblende. In one dike, however, biotite is lacking and in its place there is a small amount of augite. Plagioclase feldspar, from calcic

[1] Bull. U. S. Geol. Survey No. 150, 1898, pp. 233-236.
[2] Bull. U. S. Geol. Survey No. 530, 1913, p. 13.
[3] Diller, J. S., Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 8.
[4] MacDonald, D. F., Gold lodes of the Carrville district, Trinity County, Cal.: Bull. U. S. Geol. Survey No. 530, 1913, p. 14.

andesine to labradorite, forms a large part of the groundmass. Quartz occurs as a minor constituent in two of the dikes, and a small amount of orthoclase appears to be present in a third. Chlorite, epidote, and calcite are prominent as alteration products. The mineral composition of the rock appears to agree closely with that of the dike rock spessartite, as defined by Rosenbusch.[1]

A very rare type of dike rock is hornblende picrite, which consists essentially of hornblende.

GOLD DEPOSITS.

PRODUCTION.

Gold was first discovered in the Weaverville quadrangle in 1848; Raymond[2] states that in the fall of that year Maj. Redding took out $60,000 worth from the bed of Clear Creek. Lode mining began in 1852 with the location of the Washington mine in the French Gulch district,[3] but for many years the output from the lodes was far below that of the rich gulches and bench gravels. Lode discoveries were constantly being made, however, and the waning importance of placers in recent years has been in part compensated by increased lode production. It is impossible to make any close estimate of the amount of gold produced from the lode mines of the quadrangle, but from the fragmentary data available it is believed that the total is in excess of $15,000,000.

The following table shows the annual gold and silver production of Shasta and Trinity counties. It is believed that from 30 to 60 per cent of the lode production of each county is derived from mines within the Weaverville quadrangle.

Value of gold and silver from lode mines in Shasta and Trinity counties, Cal.

[From reports of the Director of the Mint.]

	Shasta County.	Trinity County.		Shasta County.	Trinity County.
1897	$634,632	$355,773	1901	$1,799,578	$360,237
1898	1,014,633	281,055	1902	906,283	330,785
1899	1,050,023	219,653	1903	957,602	275,342
1900	1,357,350	263,939			

[1] Rosenbusch, H., Mikroskopische Physiographie der massigen Gesteine, Stuttgart, 1907, p. 681.

[2] Raymond, R. W., Mining in the States and Territories west of the Rocky Mountains, Washington, 1874, p. 143.

[3] Trask, J. B., Report on the geology of northern and southern California: Rept. California State Geologist, Sacramento, 1856, p. 49.

Production of gold lode mines in Shasta and Trinity counties, Cal., in fine ounces, except as indicated.

[From Mineral Resources of the United States.]

Year.	Shasta County.			Trinity County.		
	Gold.	Silver.	Number of producing mines.	Gold.	Silver.	Number of producing mines.
1903	[a]34,462	[a]($214,028)	....	14,038	($184)	....
1904	31,024	($5,096)	[b]35	9,165	($80)	27
1905	27,512	8,025	25	17,020	3,759	30
1906	27,133	8,817	17	7,119	1,881	16
1907	23,986	42,465	23	8,713	1,271	19
1908	34,056	66,362	28	8,980	4,057	24
1909	47,532	27,279	28	7,342	2,144	34
1910	44,293	8,752	34	6,134	1,592	24
1911	38,193	23,585	49	14,411	10,262	24

[a] Includes gold and silver production from Shasta County copper mines.
[b] Includes copper mines.

TYPES.

The principal gold deposits of the quadrangle are fissure veins, as a rule narrow, with steep dips. Certain minor deposits known as "pockets" form a distinct type.

The fissure veins are most numerous in the slate, are more rare in meta-andesite near the slate, and in both formations are usually associated with porphyry dikes. Deposits of this type have been the best producers of the quadrangle. A second type of fissure veins comprises those which cut the quartz diorite and alaskite porphyry, particularly in the region south and east of Whiskeytown. As a rule, basic dikes occur in the vicinity of these deposits. In the Dedrick district the fissure veins have walls of hornblende schist, and granitic and alaskitic dikes occur in the vicinity. The pocket deposits are always on or near the contact of the slate of the Bragdon formation with another rock, generally meta-andesite.

DISTRIBUTION.

FISSURE VEINS IN THE BRAGDON FORMATION.

Most of the fissure veins in the Bragdon formation lie in the vicinity of the complex of porphyritic intrusives which extends from the upper part of French Gulch across the divide into Trinity County. The following table shows the principal features of the more important mines of this group, and brings out the similarity in the occurrence of the veins and their mineral content:

Principal characteristics of the most important fissure veins in the Bragdon formation.

Mine.	No. on map.	Production	Wall rocks.	Vein.	Mineralogy.	Remarks.
Whiskeytown district.						
Truscott	7	Estimated $60 000, 1887–1912.	Slate and diorite porphyry.	Strike N. 20° E.; dip 60°–80° S. Lenticular, maximum width 10 feet. Follows contact.	Quartz, calcite, pyrite, and rare chalcopyrite. Tellurides reported.	Also a small rich stringer 8 inches wide in porphyry.
French Gulch district.						
Gladstone	18	$2,500,000, 1896–1912	Slate and sandstone; soda granite porphyry in workings.	Strike east; dip vertical and steep north; local irregularities. Average width, 2½ feet.	Quartz with small amount of calcite, pyrite, galena, sphalerite, and arsenopyrite rare.	Vein developed to a depth of 2,000 feet below outcrop.
American	19	Unknown	Slate and sandstone	Strike N. 80° E. to east; dip 80° S. to vertical.	Quartz, pyrite, and arsenopyrite.	Not working. No intrusive rocks seen in immediate vicinity.
Franklin	20	$350,000, 1907–1912	Slate and soda granite porphyry.	Two veins: 1. Strike N. 5° to 30° W.; dip steep east. 2. Strike east; dip 70° N.	Quartz, calcite, pyrite, arsenopyrite, galena, and rare sphalerite.	Veins are near contact but cut both rocks.
Washington	22	Estimated between $1,000,000 and $2,000,000, 1852–1912.	Slate and meta-andesite. Many intrusives, soda granite porphyry, quartz-augite diorite, and diorite porphyry in the vicinity.	Two veins: 1. Strike north; dip 65° E. 2. Strike east; dip steep north.	Quartz, no calcite, pyrite, galena, rare arsenopyrite, and sphalerite.	Veins cut slate and meta-andesite. Not controlled by contact.
Niagara	23	Unknown; probably about $1,000,000.	Slate, conglomerate, diorite porphyry, and soda granite porphyry on dump.		Quartz, pyrite, galena, rare sphalerite, and arsenopyrite.	Not in operation.
Summit	24	Estimated $200,000	Slate and soda granite porphyry.	Two veins, crossing dike	Quartz, very small amount of calcite, pyrite, galena, sphalerite, and arsenopyrite, manganese oxide.	Ore partly oxidized. Vein productive only in porphyry. Ore pockety and very rich in spots.
Brunswick	25	$70,000, 1879–1912	Slate and diorite porphyry.	Strike east; dip 60° N	Quartz with small amount of calcite, pyrite.	Vein follows contact rather closely.
Deadwood district.						
Brown Bear	26	Estimated $7,000,000 to $10,000,000, 1875–1912.	Slate, diorite porphyry and soda granite porphyry.	Two principal veins. Strike N. 80° E.; dip north and south.	Quartz, minor calcite, pyrite, galena, sphalerite, and rare arsenopyrite.	Veins generally close to contacts. Complex of porphyry dikes and irregular masses.

Principal characteristics of the most important fissure veins in the Bragdon formation—Continued.

Mine.	No. on map.	Production.	Wall rocks.	Vein.	Mineralogy.	Remarks.
Dog Creek district.						
Delta and Trinity	28	$32,000	Meta-andesite, alaskite porphyry, and soda granite porphyry; slate short distance above.	Several small veins. Strike between east and N. 70° E.	Quartz, minor calcite, rare barite, pyrite, galena, sphalerite, and rare arsenopyrite and chalcopyrite. Manganese oxide.	
Minersville district.						
Fairview	32	Estimated $200,000	Slate; meta-andesite near by.	Strike west to N. 80° W.; dip 50°-80° N. Maximum width 20 feet.	Quartz, pyrite	Ore from $7 to $30 a ton. No intrusive seen in vicinity.

The slate wall rock is generally much crushed and sheared, so that the bedding has been obliterated and the rock altered to a glistening black slate with a shining luster and markedly schistose structure. This slickensiding has emphasized the presence of carbon in the slate by concentrating it along the shear planes, locally in sufficient amount to blacken the hands. The dikes, however, show no such shearing. Intrusive porphyries, either soda granite or diorite porphyry, are found in close association with almost all the veins. Where the intrusive is diorite porphyry, in the Truscott and Brunswick mines, the veins follow the contact of slate and porphyry. In the Summit mine the vein cuts directly across the soda granite porphyry dike. In the Brown Bear and Franklin mines the veins, though near the contact, cut both the soda granite porphyry and the slates, but tend to be best developed in the porphyry and to finger out in the slates. In the Gladstone and Washington mines, on the other hand, the veins are in the slate and do not cut the soda granite porphyry. This leads to the conclusion that the position of the veins along the contact of the diorite porphyry is merely dependent on the fact that the contact of two such unlike rocks is a favorable position for fissuring, and that the ore deposition is genetically connected with the intrusion of the soda granite porphyry.

The mineral composition is much the same in all the veins. The gangue is quartz with a minor amount of calcite and small specks of green mica. Certain sulphides, notably pyrite, galena, sphalerite, and arsenopyrite, are fairly constant, while chalcopyrite is very rare. To a certain extent the sulphides vary with the wall rock. Where the walls are soda granite porphyry, arsenopyrite is always found both in the ore and in the country rock. Galena and sphalerite are more common where the walls are slate. Much of the gold is coarse enough to be easily seen by the naked eye. Manganese oxide is not a prominent feature of any of the veins of this type, though in the oxidized ores, such as are mined in the Summit and the upper workings of the Washington, the rich pockets are marked by the sooty black powder. The surface ores in many deposits were known to have been exceedingly rich, but have now been largely exhausted.

The veins are fairly persistent both in strike and in dip. The Last Chance and Monte Cristo veins of the Brown Bear mine have been drifted for a distance of 1,400 feet and the Gladstone vein for 2,000 feet. The Gladstone vein, moreover, has been developed for 2,000 feet vertically below the outcrop. The ore shoots are generally large and fairly regular, the maximum drift length being about 500 feet. The lowest point reached in the Gladstone shaft is about 800 feet above sea level, and the veins of the Niagara group outcrop on the Trinity-Shasta divide, 7 miles to the west, at an elevation of about 4,200 feet, which gives a minimum vertical range of deposition of

3,400 feet. The veins (in meta-andesite below the slate) of the Dog Creek district have been included in this group because of their mineralogic similarity but are less persistent in strike and have not yet been explored to any great depth.

The prevailing trend of the fissures is east and west, though with many minor variations. In the western part of the French Gulch district there is also a minor north-south series.

FISSURE VEINS OUTSIDE OF THE SLATES.

Most of the important veins outside the slate area are in the Iron Mountain, Igo, and Bully Choop districts, which were not visited in 1912. In the Whiskeytown and Dedrick districts the veins are poorer in sulphides and show a smaller variety of minerals than those which cut the Bragdon formation. In several veins pyrite is the only sulphide present. Quartz is the principal gangue mineral and calcite is comparatively rare.

In the mines of the Whiskeytown district small dikes of an augite-quartz diorite, with a very large proportion of dark minerals, are near the veins. In two of the mines, the Mascot and Gambrinus, the altered wall rock is said to carry gold.

Principal characteristics of fissure veins outside of the Bragdon formation.

Mine.	No. on map.	Production.	Wall rocks.	Vein.	Minerals.	Remarks.
Whiskeytown district.						
Mount Shasta	1	$178,000, 1897–1911	Alaskite porphyry	Two veins; strike northwest; dip varying.	Quartz, rare calcite, pyrite, molybdenite; no free gold.	Ore from $4 to $43 a ton. Dike of basic quartz-augite diorite near vein.
Mascot	3	None	Basic quartz-augite diorite, near quartz diorite contact.	Two veins; 1. Strike N. 55° E.; dip 45° SE.; 2. Strike N. 50°–62° E.; dip 60° SE.; width 6 inches to 3 feet.	Quartz, pyrite, manganese oxide; ore largely oxidized.	Ore said to run $11.85 a ton; quartz diorite grades into alaskite porphyry a short distance to the north.
Gambrinus	4	$127,000, 1870–1912	Alaskite porphyry, near meta-andesite contact.	Four veins; strike N. 50° W. to west; dip 50° N. to vertical.	Quartz, pyrite, rare chalcopyrite, manganese oxide, rare albite.	Altered porphyry said to be auriferous. Basic quartz-augite diorite dike near by.
Mad Ox	5	Unknown	Meta-andesite, near alaskite porphyry intrusion.	Strike N. 22°–33° E.; dip 80° SE. to vertical; width from knife-edge to 4 feet.	Iron-stained quartz, rare calcite; no sulphides seen.	Mine not working. Ore oxidized.
Dedrick district.						
Globe	33		Hornblende schist	Strike N. 55°–70° E.; dip 60° SE.; average width 8 feet.	Quartz, albite, rare calcite, pyrite, manganese oxide.	Soda granite and alaskite porphyry dikes near by. Ore about $10 a ton. Gold more finely divided than usual.
Craig	35		do	Strike N. 70° E.; dip 45°–60° SE.	Quartz, rare calcite, pyrite, rare chalcopyrite.	

POCKET DEPOSITS.

In certain of the deposits of the region practically all the gold is contained in small scattered pockets near the surface, all of them being found at or near the contact of the black slate with some other formation, generally meta-andesite. At three localities, the Eldorado, Mad Mule, and Five Pines mines, these pockets have been found of sufficient size or close enough together to justify extensive work along the contact. Elsewhere they have been explored for only a few feet below the surface. Of the three mines, two, the Eldorado and the Five Pines, follow the contact of the slate and meta-andesite, whereas the pockets of the Mad Mule mine (fig. 3, p. 47) lie in troughs formed by irregularities in a dike of diorite porphyry.

The Eldorado perhaps represents an intermediate type between the fissure veins in the Bragdon formation and the typical pocket deposits. In this mine manganiferous quartz lies along a faulted contact between meta-andesite and slate, with more or less gouge on both walls. The movement, although following the contact in a general way, has been in part oblique to it. Hence the present line of contact is extremely serrate; sharp wedges of glistening, slickensided black slate enter the meta-andesite, and small lenticular masses of slate are completely cut off from the main body. The pockets, from one of which $2,500 worth of gold was taken, are found either in the gouge on the walls of the manganiferous quartz or in little irregular veinlets of quartz in the meta-andesite close to the inliers of slate. So far work has been profitable only in the upper levels. The fineness of the gold, however, is notably low, as $14 an ounce is said to be the average value.

In the Five Pines mine the pockets likewise follow a faulted slate and meta-andesite contact, but here they lie downhill from a vein of low-grade manganiferous quartz which crosses the contact and near irregular stringers of quartz in the meta-andesite near the slate. Along the contact of slate and meta-andesite are patches of calcite with a small amount of quartz, irregularly mixed with black slate. The pockets, of which one yielded as much as $45,000 in a distance of 44 feet, are found along the slate contact. Less commonly small pockets are found in the meta-andesite near the slate, and more rarely still in small calcite stringers in the slate close to the contact. Near several of the larger pockets small discontinuous quartz stringers cut the porphyry. The gold, however, is commonly between the calcite and slate or along cleavage planes in calcite. Pockets have been found from the surface to the water level, and always along watercourses.

In the Mad Mule mine the pockets lie along the contact of the slate with a steeply dipping dike of diorite porphyry, here again in connection with patches of calcite. The porphyry is somewhat pyritized and is cut by small quartz stringers that carry much manganese oxide.

These are looked upon as indicators of rich pockets. The slate is much sheared, especially along the contact, and as in the Five Pines mine, the pockets lie along the present watercourses.

A deposit of similar type in the vicinity of Minersville has been noted by Diller.[1] Here gold occurs in calcite lenses in black slate, which also carry a small amount of quartz. In one hand specimen of the ore three-fourths of its volume is estimated to be native gold.

The most common type of pocket deposit, however, is that in which the gold has been followed only a few feet below the surface. These pockets are found exclusively along the contacts of slate and meta-andesite, particularly in the region between Trinity Center and Minersville. Much of the early placer mining consisted in sluicing these rich surface pockets. This type of deposit has been studied by Hershey,[2] who reaches the conclusion that the pockets are the result of solution of the gold contained in pyritized zones in the meta-andesite by surface waters, and redeposition by contact with the black slate. He says, in part:

> At the contact the black rock frequently has a shining luster and a schistose structure due to shearing. This gives it imperfectly the power of a gouge to deflect underground waters. The volcanic rock near the contact has generally been decomposed, softened, and changed to a dull-brown color; it is popularly known as porphyry. In places there is a thin vein of quartz between the so-called porphyry and the black schistose material, but generally they are in actual contact or separated merely by a thin seam of ferruginous dirt. The dirt seam often carries a little free gold, but the pockets are said to be found near or where seams of quartz penetrate the porphyry downward from the contact. The gold lies in a thin, flat sheet upon the igneous rock and under the slate, and in some cases extends a short distance into the former formation, rarely into the latter. It is in the form of coarse and fine grains that have a peculiar smooth and rounded surface quite unlike the free gold in quartz veins. * * *
>
> The reason that the slate-volcanic rock contact is the great "pocket" horizon is that it is there that the gold-bearing solution first reaches a carbonaceous rock—the carbon precipitates the gold. The water may reach the contact by traveling nearly horizontally through inclined strata or by ascending under hydrostatic pressure. The sheared slate so frequently found along the contact aids in holding the solution to it while the gold is being deposited. Probably also water issuing from the slate carries the precipitating agent. For a long time the point of union between the precipitant and the gold-bearing water remains at one place at or near the contact, and thousands of dollars' worth of gold is thrown down within a space of a few cubic yards or less.

It seems clear that these pocket deposits, including both those of the three mines already mentioned and the smaller deposits, are of surficial origin and that the factor determining the deposition of the gold is the carbon of the black slates, as has been stated by Hershey. It is believed, however, that the cause of the solution of the gold is the presence of manganese oxide. Manganiferous quartz is present in the three mines of the pocket-deposit type. The writer was not fortunate enough to see any of the smaller pockets that are being

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[1] Diller, J. S. Native gold in calcite: Am. Jour. Sci., 3d ser., vol. 39, 1890, p. 160.

[2] Hershey, O. H., Origin of gold pockets in northern California: Min. and Sci. Press, vol. 101, 1910, pp. 741–742.

worked, but in all the old workings examined joints in the meta-andesite near the slate contact were in most places stained with manganese oxide.

W. H. Emmons[1] has discussed the enrichment of gold deposits in veins in igneous rocks. In the deposits considered ferrous sulphate is the precipitant, and, owing to its continual oxidation to ferric sulphate through the presence of manganese oxide, it does not precipitate gold to any extent until the water level is reached. It may be assumed, however, that in these deposits the precipitant has been the carbon of the black slates, whose efficiency is unaffected by its being in the oxidized zone, and perhaps the calcite of the small lenses as well. Moreover, as the calcite, which is present in the larger of these deposits, is dissolved, the acid solution is neutralized and becomes no longer capable of taking gold into solution. Hence deposition of gold by surface waters is here confined to a narrow zone close to the surface, and where favorable local conditions control the flow, as has been most clearly the case in the Mad Mule mine, pocket deposits of small size but extraordinary richness may be formed. In the Mad Mule a single plate of gold weighing 100 ounces is said to have been found between the calcite and the slate.

That gold is not dissolved to any extent through the agency of manganese in the presence of calcite, owing to the neutralization of the acid water by the solution of calcite, is further illustrated by studies made by Eddingfield[2] on certain gold-calcite-manganese ores of the Philippine Islands.

For the formation of such deposits as the Mad Mule the first step seems to have been the fissuring near the slate contact and the formation of small veinlets of gold-bearing manganiferous quartz, some of them carrying calcite. At about the same time came faulting along the contact, with the resultant slickensiding, concentration of the carbon of the slate along the slickensided surfaces, and the formation of gouge, with filling of lenticular open spaces along the contact by primary solutions that deposited chiefly calcite but also some quartz, pyrite, and arsenopyrite. The formation of the present pockets did not begin until a topography approaching that of the present time was attained. The course of the underground water is to a large extent controlled by the slickensided slate along the contacts and by joint planes in the more massive meta-andesite or porphyry. These waters are acid owing to the decomposition of the pyrite in the igneous rock. Whatever calcite may have been present in the manganiferous quartz stringers was soon dissolved and possibly redeposited on the already formed calcite lenses along the contacts. Later acid waters, following the same channels and no longer neutralized by the calcite, were able, through the agency of the manganese

[1] Trans. Am. Inst. Min. Eng., vol. 42, 1911, p. 3.
[2] Eddingfield, F. T., Philippine Jour. Sci., vol. 8, sec. A, 1913, pp. 125–134.

oxide, to dissolve the gold carried in the manganiferous quartz stringers or in the pyritic bands in the meta-andesite,[1] but not to transport it to any great distance, owing to the precipitating action of the carbon of the black slate. Nor can the gold thus deposited be again readily dissolved, owing to the neutralization of the solution by the calcite of the lenses along the contact. Thus a shallow zone of rich deposits is formed, the lower level of which can never be far from the original source of the gold. Rich placer deposits have been the rule wherever the streams cut the slate and meta-andesite contact.

MINERALOGY.

The primary minerals mentioned below have been noted in the deposits.

GANGUE MINERALS.

Quartz is the principal gangue mineral of all the fissure veins. It is rarely drusy, and as seen under the microscope it is generally in small interlocking grains, filled with minute inclusions. Where small fragments of the wall rock have been replaced the grain is much finer.

Calcite is almost universally present in minor amounts and is the principal mineral of the pocket deposits. Its brown color on weathered surfaces is evidence of the presence of manganese. In the Five Pines mine the fresh calcite has a distinct pinkish tinge, presumably due to a high manganese content.

Mica in the form of paragonite or sericite is common as an alteration product in the altered porphyry close to the veins. In the quartz of a few of the veins, generally close to the walls, are small specks of a dark-green mineral which appears to be muscovite, probably the variety mariposite. Under the microscope a few minute veinlets of quartz and mica were seen crossing pyrite crystals in the ore.

Albite occurs as a minor gangue mineral in the quartz of the Globe vein and was observed in microscopic grains in the ore of the Gambrinus mine. Specimens of vein quartz from the Mount Shasta mine contain kaolin, which may have resulted from alteration of original feldspars.

Barite in small tabular crystals was observed in ore from the Five Pines mine and the Red Lion claim of the Delta mine. In the Five Pines mine it is associated with pink calcite; on the Delta property it appears in part to replace alaskite porphyry and is cut by small veinlets of pyrite.

Tourmaline was found only in the ore of the Mountain Monarch prospect, in small rosettes 4 or 5 millimeters in diameter, composed of minute acicular crystals.

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[1] Hershey, O. H., op. cit., p. 742.

METALLIC MINERALS.

Arsenopyrite is common in nearly all the mines in the Bragdon formation. As a rule, however, it is found in the altered porphyry rather than in the ore itself and in the neighborhood of the porphyry rather than in that of the black slate.

Chalcopyrite is a comparatively rare mineral in the gold deposits but was noted in the quartz of the Gambrinus and Craig gold mines and, together with pyrite, in the Mountain Monarch and Delta copper prospects.

Covellite was seen only as a coating on some of the pyrite in the ore of the Mountain Monarch prospect.

Galena is an important mineral in the deposits in the veins in the slate but is not seen elsewhere. Its presence in the quartz is regarded as a sign of rich ore. It is more common in the quartz close to the black slate than near the porphyry wall rocks and is never found outside the vein.

Gold occurs in the veins both as free gold and in the sulphides. The free gold is by far the most important, as the concentrates do not often exceed 1 per cent of the ore in weight or 6 per cent in value. In many of the deposits the concentrates are not considered worth saving, and the pocket deposits contain practically no sulphides. In many of the fissure veins in the slate the gold is in plates large enough to be easily visible. Most commonly it is closely associated with included specks of black slate or occurs near the slate wall rock, and in a number of places it has been deposited close to galena, or more rarely sphalerite, in the quartz. In rich oxidized ores, such as those of the Washington surface workings or the Summit mine, gold is commonly present in small cavities in the quartz associated with iron or manganese oxide. In the pocket deposits gold may be found in irregular plates between the slate and meta-andesite or associated with manganese oxide in joint planes of the meta-andesite, but in the larger deposits of this type, such as the Mad Mule and the Five Pines, it also occurs along cleavage planes of calcite or between calcite and slate.

Manganese oxide is found in the pocket deposits and in most of the fissure veins, though it is less prominent in the veins in the Bragdon formation than in several of the others.

Molybdenite occurs in small specks in the ore of the Mount Shasta mine.

Pyrite is the most widespread of all the metallic minerals. It is found in the quartz of the fissure veins and calcite lenses, in the shear planes and small fissures in the slates, and in small crystals scattered through the porphyries, even at a distance from the vein.

Sphalerite occurs only in the veins which cut the slate and is nowhere prominent. Generally it is to be found in close association with galena.

Tellurides have been reported from a few fissure veins, but no indication of telluride minerals was seen in any of the specimens examined.

The two important gangue minerals, quartz and calcite, seem to have crystallized simultaneously. In many veins quartz is on the walls and calcite in the center, but this relation is not at all constant. In some specimens of oxidized ore the calcite has been dissolved out, leaving casts of tabular crystals impressed on crystalline quartz, showing an intergrowth of the two minerals, and certain specimens show veining of each of these minerals by small stringers of the other. Of the sulphides arsenopyrite and pyrite have migrated into the wall rock to a certain extent, but galena and sphalerite are found only in the quartz. The gold has been deposited chiefly near the black slate and to a less extent on the galena and sphalerite. Calcite is nearly always free from sulphides but is cut by small stringers of quartz, which in one specimen carry sulphides, and many of the pyrite crystals are cut by microscopic veinlets of quartz and sericite.

HYDROTHERMAL ALTERATION.

The country rocks adjoining the veins show comparatively little alteration that is directly attributable to the ore-bearing solutions. Where the walls are slate small fragments in the vein are replaced by an aggregate of quartz, sericite, pyrite, and, rarely, arsenopyrite grains. The carbonaceous matter remains unchanged and locally forms a nucleus for the deposition of minute flakes of gold. The quartz is distinctly finer grained than in the veins. Sandstone near the veins is impregnated with pyrite, and its feldspar grains are in part sericitized. Where the soda granite porphyry is in immediate contact with the vein the chief alteration consists in silicification, with the development of pyrite and arsenopyrite. At a distance from the vein the alteration consists in the sericitization of the feldspar, with the development of a small amount of secondary calcite and the chloritization and, to a minor degree, sericitization of the biotite. Chlorite and small specks of epidote are often found in the altered wall rocks, but these minerals are not especially prevalent in the vicinity of the veins.

Studies by B. S. Butler[1] have shown that near the copper deposits a part of the micaceous secondary mineral is paragonite rather than sericite. As the two are indistinguishable microscopically, the name of the more common mineral has been used in this paper.

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[1] Bull. U. S. Geol. Survey No. 430, 1910, p. 88.

In specimens of alaskite porphyry wall rock the only alteration is the development of a small amount of chlorite and scattered crystals of pyrite. Tourmaline was noted in connection with quartz, sericite, calcite, and chlorite in the altered meta-andesite of the Mountain Monarch prospect.

The changes in the meta-andesite—the uralitization of the pyroxene and the development of secondary epidote, chlorite, calcite, and quartz—are not confined to the vicinity of the ore deposits and are products of regional rather than hydrothermal metamorphism. Compared with the hydrothermal alteration of the rocks of the Sierra Nevada camps as described by Lindgren,[1] there seems to be less alteration of the walls and a smaller development of the carbonates and potash-bearing micas in the altered porphyries.

MINING CONDITIONS.

The rich surface ores of the known veins have now been practically exhausted, but the persistence of ore at considerable depth has been shown in the development of the Gladstone and Mount Shasta veins. There is no reason to suppose that these are exceptional, and though there is an undoubted decrease in tenor below the zone of oxidation, it is believed that under careful management many of the veins could be worked at a profit to considerable depths in spite of the increase in cost. At the present time the Gladstone and the Mount Shasta are the only mines which are not developed almost entirely by tunnels.

The region is particularly favored in its natural features, as the rugged topography allows extensive development by tunnels. The ore is free milling and easily crushed, and water power is everywhere available. In the northern part of the area timber is abundant.

The peculiar pocket deposits of the area have given rise to a class of prospectors known as "pocket hunters." These men follow carefully the contacts of slate and meta-andesite and by systematic panning discover many rich pockets by tracing the particles of gold in the soil to their sources. As soon as a pocket is gouged out and the joint plane or contact where it was found no longer shows colors, the place is abandoned. Possibly future exploration of pocket zones along the contact to somewhat greater depths, particularly where there are calcite lenses, may reveal other deposits of the type of the Five Pines mine.

It is impossible to say whether new discoveries of the fissure-vein type may be expected. Areas in the vicinity of masses or dikes of soda granite porphyry in slate of the Bragdon formation should be prospected carefully.

[1] Lindgren, Waldemar, Characteristic features of California gold-quartz veins: Bull. Geol. Soc. America, vol. 6, 1875, pp. 221-240.

Many of the failures in lode mining have been due to the installation of mills more elaborate than the size of the ore body justified. The owners of some of the smaller veins which are worked profitably with a mill of two to five stamps would lose money by attempting to operate on a larger scale.

MINES.

WHISKEYTOWN (STELLA) DISTRICT.

The Whiskeytown or Stella district is probably second to French Gulch in total output, though none of the mines are at present large producers. The mines lie along the edge of a mass of alaskite porphyry which borders a larger area of quartz diorite and is intrusive into the meta-andesite. The slates and conglomerates of the Bragdon formation appear near the heads of Whiskey and Grizzly creeks. Numerous small dikes of quartz-augite diorite cut the alaskite porphyry and granodiorite, and two larger dikes of diorite porphyry cut the Bragdon formation in the northern part of the district.

MOUNT SHASTA MINE (1).[1]

The Mount Shasta mine (Mount Shasta Mining Co., owner; Guy M. Vail, manager) is in the quartz diorite mass which covers the southeast corner of the quadrangle and is about 3 miles south of Whiskeytown and a mile west of the eastern boundary of the quadrangle.

The deposit was discovered in 1897 by George Leversay, who, with his partners, took out 88 tons of oxidized ore that ran $48.44 to the ton, giving a production of $4,263. It was sold to the Mount Shasta Gold Mines Corporation, which continued development and mined altogether from the first six levels (398 feet) a total of 4,072 tons, averaging $42.69 a ton, or $173,876, giving a total production of about $178,000.[2] The old company failed in 1905, largely through unfortunate ventures in other directions, and the property remained idle until 1911, when the present company began development work on the seventh level (465 feet). In July, 1912, four men were employed.

The country rock of the region is quartz diorite, but the ore deposit itself lies within an elongate mass of alaskite porphyry about 300 feet wide. This rock is fine grained, dense, and aphanitic. The only phenocrysts are small quartzes, up to 2 millimeters in diameter, and rare feldspars. In places, especially near the vein, the rock is much sheared and has the appearance of a flow-banded rhyolite. Secondary quartz has been introduced in lenses along the shear planes.

[1] Numbers refer to map (Pl. II).

[2] Figures furnished by Mr. G. M. Vail.

Under the microscope the rock shows small phenocrysts of quartz and albite feldspar, irregular and broken but fairly fresh. The groundmass is a microcrystalline aggregate of quartz and feldspar, the former predominating. Small patches and shreds of sericite and chlorite indicate secondary hydrothermal action. Irregular but roughly parallel veinlets of quartz and sericite cut the rock.

Where seen adjacent to the vein (on the seventh level) the porphyry is in places partly silicified; elsewhere near the vein it is chloritized; in both situations a small amount of pyrite has been introduced. The zone of intense alteration of the porphyry does not extend more than 15 feet from the vein, and the silicified and chloritized porphyry carries no gold. In the siliceous phase the alteration consists in the introduction of quartz along microscopic but closely spaced fissures. Calcite appears in small specks, particularly near the feldspar phenocrysts, and in thread-like veinlets that cut the quartz. Where chloritization has been more prominent, chlorite, with a small amount of calcite, replaces the groundmass and a part of the feldspar phenocrysts. The quartz and feldspar phenocrysts also contain shreds of sericite.

About 200 yards northeast of the shaft, near the border of the alaskite porphyry, is a small outcrop of a very fine grained quartz-augite diorite which shows a larger proportion of ferromagnesian minerals as well as a finer grain than the typical diorite of this vicinity. Augite, almost entirely altered to chlorite, is the dominant mineral. Quartz and andesine feldspar are subordinate.

The two veins worked are parallel in strike and about 50 feet apart on the surface. Near the surface the dip of both veins is to the southwest. The dip of the east vein changes to northeast between the second and third levels, and that of the west vein between the fourth and fifth levels.

The ore is white quartz, as a rule so much sheared and fissured as to be very friable. In places, however, it is firm and massive and is frozen to the walls. Even where it is most completely shattered some large individual crystals an inch or more in length may be seen. A little calcite in small crystalline masses is scattered irregularly through the quartz. Near the walls and in the altered wall rock inclosed in the quartz are small patches of sericite. Rarely a little kaolin is also present.

Pyrite is the only metallic mineral of any abundance. It is found in bands of crystals in the quartz generally close to the walls and to a slight extent as an impregnation of the altered alaskite porphyry. In the shattered white quartz from the seventh level small specks of molybdenite were seen. This mineral has not been observed in the ore of the upper levels and so far as known does not occur elsewhere in the quadrangle.

Work at present is confined to drifting toward the north along the west vein in the expectation of encountering the ore shoot mined on the level above. The quartz in which the drift was being run in July, 1912, averaged about $4 a ton.

BLACKSTONE PROSPECT.

About 1,200 feet north of the Mount Shasta mine the Blackstone prospect, in quartz diorite, shows ore composed of auriferous pyrite in a gangue of quartz and dolomite cut by minute threads of specularite.

MOUNTAIN MONARCH PROSPECT (2).

The Mountain Monarch is a copper prospect about 2 miles due south of Whiskeytown, on the flat-topped ridge west of the valley of Clear Creek. The workings consist of a small shaft on the top of the ridge at an elevation of about 2,400 feet, filled with water at the time of visit, and a tunnel in the hill, about 400 feet below the shaft, which has been driven 720 feet of the 1,200 feet that it has been calculated is necessary in order to reach the ore body shown in the shaft.

The country rock at a distance from the ore is a much sheared and epidotized meta-andesite, in places slightly pyritized along the joint planes. The prospect is not far from the contact of the meta-andesite and quartz diorite, and small dikes of alaskite porphyry cut the meta-andesite in the vicinity of the tunnel, though none were seen in the tunnel itself.

A few tons of ore has been stacked near the shaft. A part of it is almost entirely pyrite, in crystalline masses, in which the crystals vary from minute specks to bodies about 3 millimeters in diameter, but here and there are small amounts of glassy quartz. Small velvety feather-like clusters of minute tourmaline needles are common in parts of the pyrite, especially where the grain is finest. Besides the pyrite the only other metallic minerals present are rare specks of chalcopyrite distributed irregularly throughout the ore and a coating of covellite over a part of the pyrite. Other specimens of the ore consist of meta-andesite, in part replaced by pyrite and accompanied by small clusters of tourmaline needles, chlorite, epidote, and a little quartz.

No data could be obtained as to the size or shape of the ore body or the value of the ore.

MASCOT MINE (3).

The Mascot mine (Gray & Rossi, owners) lies about 2½ miles southeast of Whiskeytown. The workings consist of two tunnels, on the upper of which a vein has been followed for about 200 feet. It is planned to crosscut the veins in the lower tunnel and to erect a 10-stamp mill. So far there has been no production.

The country rock is quartz diorite, here rather deficient in ferromagnesian minerals, grading off within half a mile to the west and northeast into the coarser-grained type of alaskite porphyry. The diorite is cut by a dike of fine-grained quartz-augite diorite, 100 feet or more in width. It is similar in mineral composition to that of the Mount Shasta mine, except that the augite is less altered. A similar dike about 40 feet wide has been crossed in the lower tunnel.

The two veins lie entirely within the basic dike near the contact with the diorite. At one point there is also a little quartz on the contact of the dike, but it has not been worked. One vein strikes N. 55° E. and dips 43°–52° SE.; the other strikes N. 50°–62° E. and dips 57°–70° SE. Only the first has been developed. Its width varies from 6 inches to 3 feet. The quartz is in places much crushed, and there is always considerable gouge on the hanging wall and locally on the footwall as well. The quartz is as a rule distinctly crystalline, and small vugs are common. The ore is entirely oxidized with the exception of a few partly altered specks of pyrite. Generally it has a platy appearance, with layers of quartz 2 to 4 millimeters thick separated by dark planes of manganese oxide. Manganese oxide is much more prominent than in other mines in the quadrangle and gives the quartz a dark-gray appearance, diversified here and there by minute spots of yellow iron oxide.

Two ore shoots have been prospected to some extent by raises. These are said to be each about 100 feet in length along the drift and to show a value of $11.85 a ton.

GAMBRINUS MINE (4).

The Gambrinus mine (Shasta Monarch Mining Co., owner; T. W. Rogers, superintendent), lies on the east bank of Whiskey Creek directly opposite Whiskeytown. The deposit was discovered about 1870 in the course of placer mining and has passed through several hands. The earlier work consisted of gophering along rich surface streaks. The total known production is $127,000, which is exclusive of an unknown amount obtained by "snipers" and lessees. The present company has been in possession for the last three years and up to July, 1912, had produced about $5,000.

The veins lie in alaskite porphyry near the contact with meta-andesite. On the opposite side of the stream and a few hundred feet to the north is an outcrop of a basic dike similar to that at the Mascot and Mount Shasta mine.

The alaskite porphyry is of the fine-grained type characteristic of the vicinity. Near the veins it is a blue-gray rock, much jointed and stained by iron oxide, carrying small phenocrysts of quartz and feldspar.

Four veins are exposed on the property. The development work consists of shallow surface workings and a crosscut from a few feet above the stream level, with drifts on the two southwestern veins and a lower level 40 feet below that was filled with water in July, 1912.

The veins are approximately parallel and have strikes varying from N. 50° W. to west and dips from 45° N. to vertical. The three northeastern veins all lie within a 60-foot zone. In these veins the quartz forms irregular lenses in zones of crushed alaskite porphyry, 3 or 4 feet wide. Small grains of albite were observed under the microscope in the quartz near the walls. These crushed zones are persistent and are drifted on when the quartz pinches out. The ore in the upper workings is oxidized but shows considerable pyrite in the pan, as well as free gold. The quartz of the northeastern vein carries no manganese. On the main level there is a small amount of pyrite together with free gold. Tellurides are reported, but their presence is doubtful. Small copper stains are seen here and there in the quartz. The alaskite between the veins is silicified and carries considerable pyrite. Assays of this altered rock for the 27 feet between two of these veins is reported to have shown a tenor of $8 a ton, practically all of which was in the pyrite. Under the microscope, the only apparent change aside from the introduction of pyrite is the development of chlorite and possibly a slight silicification of the groundmass. A few patches of coarsely crystalline pyrite occur in the porphyry. The crystals of pyrite may be as much as 6 or 8 millimeters across and are said to be barren.

The southwestern vein is not exposed on the surface and is more distinct and regular than the other three. It consists of 1½ feet of manganiferous quartz carrying free gold. No calcite was seen in any of the ore from this mine.

On the lower level, which was not accessible when the mine was visited, there have been found, according to Mr. Rogers, small amounts of chalcopyrite with which free gold is often associated.

A 10-stamp mill is now being set up on the property to replace the small prospecting mill formerly used.

MAD OX MINE (5).

The Mad Ox mine (Caribou Gold Mining & Power Co., Trinity Center, owner), on the south side of Mad Ox Gulch near its junction with Whiskey Creek, has not been in operation for the last two years. No data could be obtained as to former production or value of the ore.

The vein lies in a zone of intensely sheared meta-andesite 4 to 6 feet wide, near an intrusion of alaskite porphyry. The alaskite where close to the vein is silicified and in part replaced by calcite. The strike of the vein is N. 22°–33° E. and the dip between 80° SE. and vertical. In width the vein varies from a mere streak of gouge to a maximum of 4 feet. The longest portion of the vein that is wide enough to stope is about 100 feet long. The ore is somewhat iron stained quartz with a little calcite but carries no visible sulphides.

MAD MULE MINE (6).

The Mad Mule mine (Mad Mule Gold Mining Co., of San Francisco, owner; T. W. Briggs, superintendent), formerly the Banghart, is one of the best examples of the pocket type of deposit found in the quadrangle. The mine occupies almost the whole length of Mad Mule Gulch, a tributary of Whiskey Creek about 3 miles north of Whiskeytown. The ground was located and the surface sluiced in the early fifties. At that time the length of claims allowed was only 200 feet, and as the deposit continues for nearly a mile the number of old workings is tremendous. Mr. Briggs estimates that the total production has been about a million dollars, exclusive of a large but unknown amount taken out at different times by "snipers."

The ore lies close to a diorite porphyry dike which cuts the meta-andesite, the alaskite, and the slate and conglomerate of the Bragdon formation.

The intrusive rock is extremely striking in appearance, large white feldspars, up to a centimeter in length, being thickly studded through a fine-grained gray groundmass containing minute hornblende needles. Away from the zone of weathering, which has a maximum depth of about 50 feet, the rock is generally fresh and hard. A little pyrite scattered in small cubes throughout the rock constitutes the only indication of hydrothermal alteration. Under the microscope the feldspar phenocrysts appear to be albite grading toward oligoclase. The hornblende is completely altered to chlorite, together with some secondary calcite and a little iron oxide. The groundmass is made up of minute feldspar microlites. Calcite also occurs in irregular patches and microscopic lenses and fissures. In many of these there is an outer border of quartz, suggesting that an open cavity had been first lined by quartz and later filled with calcite.

At the west end, where the workings have been most extensive, the dike is about 150 feet wide. Its strike is here generally west, though with many local variations, and its dip 40°–60° N. Farther downhill to the east, at an elevation of 1,900 feet, where the company is running its present tunnel, the width is only about 12 feet and the dip nearly vertical. The dike, though slightly faulted here and there, is comparatively free from the intense shearing that characterizes the slate, meta-andesite, and alaskite porphyry on its walls.

The alaskite porphyry carries prominent quartz phenocrysts and is intermediate in grain between the extremely aphanitic type found on South Fork Mountain and the more granitic phase exposed along the stage road east of Whiskeytown.

The Bragdon formation as represented in the vicinity of the mine consists chiefly of black carbonaceous slate, much sheared and similar to that found in connection with the ores of the French Gulch district. Near the surface iron staining is common, and a few small circular rosettes of gypsum needles are to be seen on the shearing planes of the slate.

The workings consist of a large number of tunnels along the walls of the dike. They are more numerous and, according to local report, find richer ore on the hanging wall. Along the contact and in the porphyry and slate to distances of a few feet from the contact are small quartz stringers 1 to 2 inches wide. The quartz is honeycombed with cavities, many of which are partly filled with sooty manganese oxide. Many of the cavities are drusy, with small quartz prisms, 2 or 3 millimeters long, growing out from the flat faces of larger crystals. Others are interstitial between larger quartz crystals, and in many of these minute manganese dendrites are arranged along two series of lines intersecting in rhombs, which suggest that the manganese was deposited along cleavage cracks in calcite and that the cavity was formed by the leaching out of calcite. Other cavities are in the form of small parallel gashes in the quartz. These are commonly irregular in detail, though in a few of them the outlines are so sharp and clear as to look like cuts made by a saw. These cavities also appear to have been formed by the leaching out of calcite. The slate is, moreover, cut by numerous small stringers of pyrite and calcite. According to Mr. Briggs, this pyrite is auriferous. No arsenopyrite was found, but some arsenic is said to be present in the concentrates. So far as could be observed, no work has been done on veinlets of the type just described.

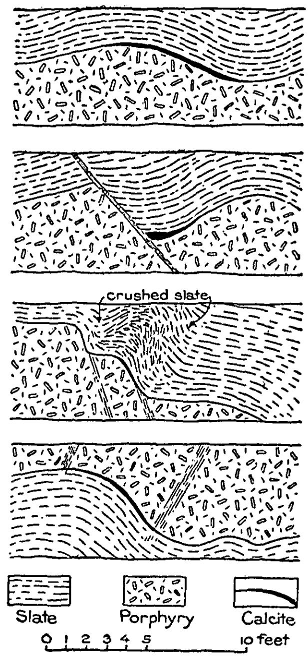

FIGURE 3.—Sketch showing position of pockets, Mad Mule mine, north of Whiskeytown, Cal.

The ore mined is almost entirely calcite, which occurs at intervals along both hanging and foot wall in small lenses known as "points." (See fig. 3.) These points have a variety of forms. The common form is a flat lens of calcite generally not over 4 inches thick, deposited in the trough formed by some irregularity in the contact of the dikes and slates. Most commonly the calcite is not directly in the crotch of the trough but along one side, tapering out toward the crotch. Such "points" as have been mined on the footwall side of the dike seem to be most commonly in the reverse position—that is, to be formed near the top of an arch rather than in a trough. These calcite lenses are as a rule not more than 3 or 4 feet in length along the strike and have been followed upward for as much as 20 or 30 feet. The calcite is rarely drusy, but here and there small acute rhombohedral crystals project into open spaces. Very minor amounts of quartz as small patches are inclosed in the calcite and are apparently contemporaneous with it. In some specimens small specks of a green micaceous mineral were seen.

Pyrite is the only sulphide present, but it is comparatively rare in the calcite. It is found in small lines traversing the ore and in scattered cubes. In the troughs, all of which are present watercourses, it occurs near the ends of the calcite lenses, though within the slate, as small octahedra, unmodified by other forms.

Gold has been mined only in the "points." Most commonly it forms a thin film on the surface of the calcite at the junction with the slate, rarely extending to plates of noticeable thickness. It is said that the largest single piece of gold taken from the mine was in the form of a plate nearly a quarter of an inch thick and weighing over 100 ounces. Gold also occurs in much smaller masses entirely within the calcite, here following the cleavage planes. Invariably, however, it is close to the slate, being nowhere, as far as could be seen, over half an inch distant. The intersection of the manganese-bearing quartz stringers referred to above with the calcite of the "points" is regarded as an indication of a rich pocket.

The "points" mined have been chiefly on the hanging-wall side of the dike and all within the upper 600 feet. Moreover, all the "points" have been found comparatively near the surface. Few of the tunnels are more than 200 feet in length, and in the longest, about 1,000 feet long, pockets had not been mined beyond the first 500 feet, which would be equivalent to not more than 250 feet in depth below the surface. All these facts indicate that the gold content of the pockets is related to the present surface. Such an origin is likewise indicated by the position of the pockets which are closely connected with the present watercourses.

TRUSCOTT MINE (7).

The Truscott mine (John Martin, owner), formerly the Emigrant, is situated near the head of Grizzly Gulch, about 2 miles northeast of the Tower House and a mile west of the head of Mad Mule Gulch. The mine was discovered about 25 years ago and has produced about $60,000, of which $12,000 was taken out in the last three years. The veins have been developed by several tunnels at two levels 40 feet apart.

The principal vein consists of lenses of quartz along the footwall contact of a dike of andesite porphyry with black slate. The average strike of the contact is N. 20° E. and the dip 60°–80° W. The width of the dike is about 300 feet. Some ore has also been found on the hanging-wall side, but none of it has been developed.

The ore occurs in large lenses along the contact. The only developed lens shows a length of about 100 feet and a greatest width of 10 feet. At the end the lens tapers down to a mere streak of black gouge along the contact. This was followed for about 30 feet and a second lens encountered. All the quartz is said to be workable and to carry from $10 to $15 a ton in free gold. The gangue consists of white quartz with a small amount of calcite, much mixed with black slate, but without porphyry. The only metallic mineral observed in the ore was pyrite, though small copper stains were seen and chalcopyrite is said to be present in small amounts. The pyrite occurs in minute crystals in the quartz and the slate, but not, so far as could be observed, in the calcite. Branching out from the main vein into the porphyry are numerous small stringers of manganiferous quartz.

On the upper level a small vein 4 to 8 inches wide branches off into the porphyry at a small angle. Here the ore is iron-stained quartz much mixed with altered porphyry and carrying much visible gold in association with partly oxidized pyrite. The ore from this small vein is said to pan between $100 and $300 a ton.

BRIGHT STAR MINE.

A short distance northeast of the Truscott is the Bright Star mine, which was worked to a small extent during a local boom a few years ago but is now abandoned.

FRENCH GULCH DISTRICT.

PRODUCTION AND GENERAL FEATURES.

The French Gulch district is the oldest lode-mining district in the quadrangle, the Washington, the oldest mine in the region, having been located in 1852. The following fragmentary records of production give some idea of the importance of the mines in this district:

Production of French Gulch district.

	Gold.	Silver (ounces).
Year ending September, 1854 [a]	$53,232	....
1855 (8 months) [a]	22,132	....
Year ending July 1, 1869 [b]	50,044	....
Year ending July 1, 1871 [c]	44,639	....
Year ending May 31, 1881 [d]	38,500	....
1909 [e]	418,622	1,709
1910 [e]	560,144	4,683
1911 [e]	420,451	3,923

[a] Production of the Washington mine. Trask, J. B., Report on the geology of northern and southern California: Rept. California State Geologist, 1856.
[b] Chiefly Washington mine. Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870.
[c] Idem, 1872.
[d] Second Rept. California State Mineralogist, 1882. Apparently includes placer production.
[e] Mineral Resources of the United States.

The mines of the district lie within the area of slate and conglomerate of the Bragdon formation, which begins at Tower House and extends northward to the border of the quadrangle. With the exception of the Eldorado, which is more closely connected with the pocket type, all the deposits are simple fissure veins and show a close mineralogic similarity. With one exception all these veins are closely associated with intrusive soda granite porphyry or diorite porphyry, chiefly the former.

The principal fissures trend nearly east and west, though a few have a northerly strike.

ELDORADO MINE (8).

The Eldorado mine (J. G. Connors, owner; Garvin & Gatney, lessees), is on the west side of Mill Creek about half a mile south of the Tower House. The property was located by William Paul about 1885, and the total production has been estimated at $25,000, of which $3,500 has been obtained by the present lessees between August, 1911, and July, 1912.

The lode lies along the fault contact of meta-andesite and slate, which strikes about N. 20° W. and dips 50°–70° E. The only working now accessible is a 400-foot drift at an elevation of 1,250 feet. There is much gouge along the contact and a part of the faulting has been oblique to the original contact, resulting in sharp wedges of slate that enter the meta-andesite at small angles and small lenses of much-crushed slate that are included in the meta-andesite at 2 feet or less from the contact.

Quartz occurs in small lenses about 2 feet in width along the slate walls and in the meta-andesite, especially near the slate. The quartz is somewhat drusy, though the vugs are all small, never more than 2 centimeters in greatest diameter. The vein quartz is much mixed with fragments of meta-andesite, whose uncertain boundaries imply some replacement. A little sericite accompanies the altered meta-andesite in places. No calcite was seen in any of the ore.

On this level the ore is almost completely oxidized. Sooty manganese oxide partly fills many of the druses. Blotches of iron oxide show the alteration of pyrite. On the lower level, 90 feet below, pyrite was found in the quartz, but is said to have proved barren, all the values being in free gold.

The gold occurs entirely in pockets in the quartz and gouge. The richest pocket found, from which $2,500 worth of gold was taken, was entirely in the gouge between quartz and meta-andesite. Other rich pockets are in the form of quartz veinlets, generally less than an inch wide, in the meta-andesite near the infaulted lenses of slate. These veinlets carry visible gold in association with specks of iron oxide and in small flakes lining minute druses. So far as could be observed, the rich quartz was free from manganese.

The gold is noticeably light colored and its fineness is much below the average for the district. It is said that its average value is about $14 an ounce and that some of it falls as low as $12. No intrusive rock has been encountered in the workings, so far as known, and none was seen on the surface in the vicinity, though the ridge was not examined in detail.

GLADSTONE MINE (18).

The Gladstone mine (Hazel Gold Mining Co., owner; J. O. Jillson, managing director; E. Young, superintendent) lies on the north side of Cline Gulch, about 5 miles by road from the town of French Gulch. It was originally located in 1896 by T. Cumming. After the oxidized ore was exhausted the mine changed ownership more than once and was purchased by the present company in 1901. The production previous to 1901 was about $85,000. From February, 1901, to June, 1912, the production has been, in gold bar, $2,389,491.78; in concentrates (net), $109,739.90; total, $2,499,231.68. Under present conditions the annual production is about $360,000.

The steep topography of the region has made it possible to mine the upper 1,000 feet of the vein by means of tunnels. The lower portion is worked from a blind shaft on the main adit (Ohio) level, which in October, 1912, had reached a depth of 1,080 feet. This part of the vein is developed by three levels. The exhausted stopes and upper workings are filled with the waste obtained in crosscutting.

The company owns a power plant on Crystal Creek which furnishes power for the mill, electric haulage, and outside lighting. The power for the hoist and pump is supplied by the Northern California Power Co. There is a 30-stamp mill, four Wilfley tables, and four vanners, the whole plant having a capacity of about 100 tons a day.

The country rock of the vein consists of slate, sandstone, and conglomerate of the Bragdon formation. The slates show great contortion, with much minor faulting and variations of dip. Conglomerate and sandstone are present only in minor amounts.

The vein itself differs from most deposits of this type in that it does not cut any igneous rocks. On the adit level several hundred feet from the vein is a small dike of much altered diabase. The dike is about 2 feet wide and much broken by the numerous small faults that cut the slate but do not affect the ore. On the fourth, fifth, and sixth levels, which were not accessible at the time of the writer's visits, the crosscuts from the shaft to the vein encountered a soda granite porphyry somewhat similar to that seen at the Milkmaid mine and elsewhere, though more granitic in texture. According to Mr. Young, this rock occurs in irregular masses about 150 feet south of the vein. These vary from a few feet to more than 40 feet in length and occur nearly vertically one over another. There is a small amount of gouge at the contact with the slate. No porphyry was found below the sixth level. Apparently these masses represent irregular apophyses from some large mass below. The most numerous phenocrysts are biotites from 1 to 3 millimeters in diameter in rough parallel arrangement. There are also a considerable number of kaolinized oligoclase feldspar crystals from 2 to 4 millimeters in length. Quartz is in clear distinct grains, many of which show embayments due to magmatic corrosion. The groundmass consists of minute crystals of quartz and feldspar. It also contains a few grains of a colorless mineral, probably garnet. The alteration shown is entirely such as could be accomplished by surface waters, and no minerals characteristic of hydrothermal alteration are to be seen. In fact, there seems to be little or no hydrothermal alteration of any of the wall rocks as a result of the introduction of the vein-forming solutions, though in places thin bands of sandstone are impregnated by pyrite and rarely the slate near the vein is silicified.

The vein is inclosed in a zone of much crushed slate and sandstone 60 or 70 feet in width, but within this zone the vein itself is irregular. Where the walls are slate it tends to break up into small anastomosing veinlets, which must be worked as a whole, involving the mining of much waste material. In the conglomerate and sandstone the vein is much more distinctly defined, though narrower. In the crushed slate the greater proportion of quartz is on the footwall side of the crushed zone. Gouge is nearly always present on both walls. The common width of the ore as stoped is 2½ feet, though in a few places it reaches a width of 12 feet. Along the adit level the vein has been followed for a distance of 2,000 feet. The present depth of working is about 1,000 feet below the adit level and 2,000 feet below the outcrop.

The strike is east with small local variations. From the summit of the outcrop to the adit level, 1,000 feet below, the vein is vertical. From the adit to the seventh level the dip is over 60° S., but below the seventh level the dip changes to steep north. This change in dip, together with the fact that the vein is much tighter and no longer carries the large amount of gouge that characterizes it on the upper levels, has led to the belief that the vein splits between the sixth and seventh levels and that it is the northern branch which has been followed. It is planned to test this hypothesis by crosscutting to the south from the ninth level.

The ore is, as a rule, massive white quartz, showing in places minute fissuring but very rarely any tendency toward crystal forms. According to Mr. Young, the quartz that occurs within conglomerate or sandstone walls tends to be more crystalline and vuggy. Such vugs as were seen were very small, not over a centimeter in length, and the individual quartz crystals are all under 3 millimeters in length. Most specimens of the vein quartz have a gray to bluish color due to the intimate mixture of fragments of slate wall rock with the quartz. A few small gray bands in the quartz appear to be due to shearing and consequent smearing out of slate fragments in lines parallel to the walls. Calcite is present in small amount throughout the ore. It is generally in small specks not over 1 or 2 centimeters in diameter but more rarely forms distinct lenses several inches long. Sericite is developed to a small degree in the replaced fragments of slate in the quartz.

The metallic minerals of the ore are pyrite, free gold, galena, sphalerite, and arsenopyrite. Pyrite is by far the most common of these. In the quartz itself it occurs in minute crystals less than a millimeter in size and almost invariably in close association either with the included fragments of slate or with the slate of the wall rock. In thin bands of sandstone in the wall rock pyrite is commonly present in small amount, scattered through the rock in minute crystals. In the carbonaceous slate, however, the pyrite does not occur as an impregnation but most commonly in small veinlets generally less than 5 millimeters in width, associated with a small amount of quartz. So far as could be observed, pyrite is not present in the calcite. The other sulphides, galena, sphalerite, and arsenopyrite, are extremely rare and are not found outside of the vein itself. Galena is present in small cubes, almost always close to the walls. The largest seen was about 2 millimeters. Sphalerite occurs in very minute specks and is much less common than galena. The presence of arsenopyrite is indicated by a small percentage of arsenic in the smelter returns of the concentrates, and the small white metallic specks seen here and there in the ore are shown to be this mineral when examined microscopically. The total of the concentrates forms less than 1 per cent by weight of the ore milled, although about 6 per cent of its value. Visible gold is of less common occurrence than in the other mines of the region, but many small specks are seen in the quartz near the included fragments of slate or the slate walls. About 94 per cent of the value of the ore is in free gold, recovered on the plates of the mill.

In the upper workings three separate ore shoots were mined. Below the adit level the two western shoots had joined and between the sixth and seventh levels the third ore shoot joined the others (fig. 4). The maximum drift width of any ore shoot was about 500 feet near the junction of the central and westernmost shoots, and the minimum slightly less than 200 feet.

In the oxidized zone, which, according to Mr. Young, reached a depth of only about 75 feet, scattered patches of very rich ore were encountered. Below this zone, however, the tenor of the ore has been rather even, the only noticeable change being a slight increase in the amount of arsenopyrite. The ore as milled runs about $10 a ton, but this is lower than the value of the quartz, as a large amount of waste must always be milled and everything which when panned shows an estimated tenor of $3 or over is mined. The good ore of the ore shoots carries from $30 to $50 a ton, and some small stringers and patches may run up into the hundreds of dollars.

This mine has been developed to a greater depth than any other in the Weaverville area, and the fact that ore has been followed for

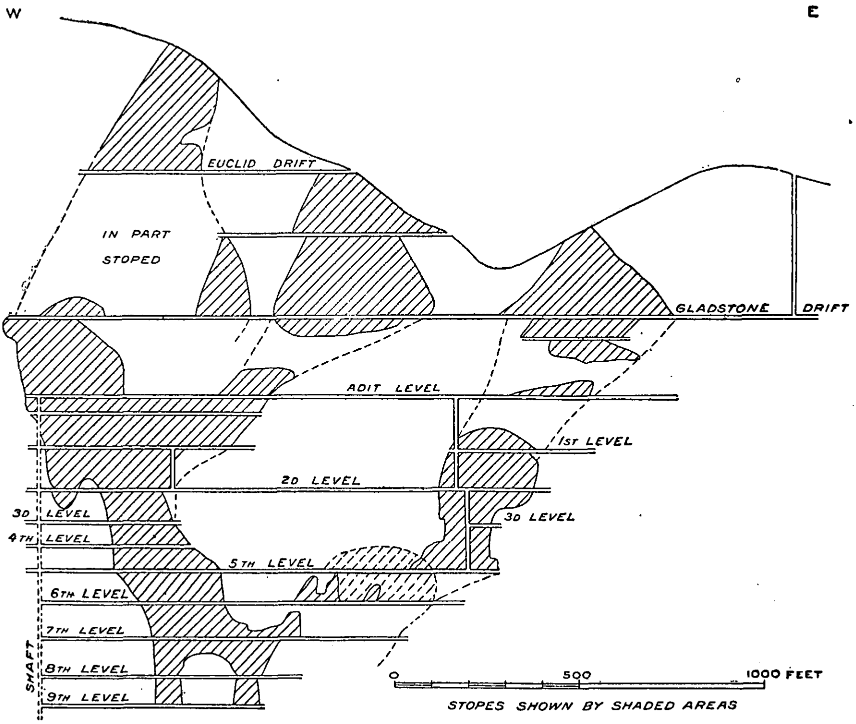

FIGURE 4.—Section along Gladstone vein, near French Gulch, Cal., showing position of ore shoots.

a vertical distance of 2,000 feet should be a good indication for the persistence in depth of other deposits of this type.

AMERICAN MINE (19).

The American mine was located in 1887. The surface ores were very rich, and it is reported that $2,000 was obtained from ore crushed in a hand mortar.[1] The workings occupy the ridge north of Cline Gulch between Clear Creek and J-I-C Gulch and consist of tunnels at several elevations between 2,500 and 3,150 feet. The

[1] Eighth Ann. Rept. California State Mineralogist, 1888.

mine has not been in operation for several years and many of the tunnels are caved. The production is unknown.

The country rock is slate and conglomerate in the upper workings and entirely slate below. Near the vein it is much fissured and disturbed but maintains a general dip to the south at varying angles. No igneous rock was seen either in the workings or on the dumps.

The vein lies in a narrow zone of much-crushed slate and varies in width from a feather edge to a maximum of about 3 feet. It has been stoped only in the eastern portion. The strike is from N. 80° E. to east and the dip from vertical to 80° S.

The unoxidized ore, so far as could be seen from the specimens picked from the ore bin, closely resembles that of the Gladstone mine in general appearance. Like the Gladstone ore, much of it has a bluish-gray color, due to specks of carbonaceous matter from the slate, and contains many small angular fragments of slate surrounded and partly replaced by quartz. The quartz contains numerous vugs and shows a crystalline form more commonly than that of the Gladstone ore. Most of the crystals appear to have grown outward from the slate fragments included in the vein. No calcite was seen in any of the specimens collected.

The metallic minerals appear to be rather less in quantity than in the Gladstone ore. Arsenopyrite, pyrite, and gold were the only metallic minerals seen. All of them were found close to the wall or near included fragments of slate. Arsenopyrite is the most common and is found in fair-sized crystals (2 millimeters or less) in the quartz and at the contact with the quartz and slate, both the walls and the included fragments. Pyrite is not common and occurs only close to the wall and in the slate. Gold was seen in small plates and imperfect crystals close to the contact of quartz and slate and in the dark bands in the quartz.

FRANKLIN MINE (20).

The Franklin mine (Western Exploration Co., owner; H. F. Musser, manager) is on the north side of French Gulch, about 3 miles northwest of the town. It is developed by adit levels at elevations of 1,950 and 2,055 feet, connected by a raise on the vein, and by a lower level 130 feet below the main level, reached by a winze. Drifts have been run on the vein in all three levels. As far as possible the stopes have been filled with waste. The large proportion of waste which it is necessary to mine brings down the value of the ore milled to about one-third of the assay value of the quartz. The ore is crushed in a 10-stamp mill on the neighboring Milkmaid property, and the concentrates are saved on four vanners. The mine is said to have been located in 1852, and is therefore one of the oldest in the State. The earlier production is unknown. The production for the last five years, according to Mr. Musser, was $350,000. In July, 1912, a force of 14 men was employed, and two lessees were working on the east end of the vein on the lower level.

The vein cuts both the slate and a mass of intrusive soda granite porphyry. A few hundred feet to the north the slate overlies a mass of meta-andesite. Dikes of diorite porphyry and quartz diorite porphyry outcrop a short distance to the south. The slate is here much sheared and crushed, having a glistening appearance due to the close slickensiding.

The intrusion of soda granite porphyry is irregular in form, but appears to occupy the valley of French Gulch at this point and to extend for about 1,500 feet northward. As seen in the mine workings the northern contact dips to the north, the upper workings being in slate and the lower in soda granite porphyry. The slate, except for the crushing and shearing, does not show any alteration near the vein. The porphyry, on the other hand, is altered and impregnated by arsenopyrite and pyrite. Under the microscope this change is seen to consist of the sericitization of the feldspar, with some development of secondary calcite, and the complete alteration of the biotite to a mixture of chlorite and sericite with specks of epidote. Sericite shreds also occur in the groundmass, which may be somewhat silicified as well.

Two veins have been followed to some extent in the Franklin workings; one with a strike of N. 5°-30° W., and a steep dip to the east, the other with a strike approximately west and a dip about 70° N. The intersection of the two veins has not been discovered. The northward-striking vein is in the extreme western part of the workings and has been stoped on the main level for about 70 feet only. A short distance above the level it passes out of the porphyry and into the slate, where it splits up into a series of small stringers. The other vein has been followed in all for 700 feet on the main level, where the walls are porphyry, and for smaller distances on the upper and lower workings. In the upper level (105 feet above the main level) the walls are slate and the vein less defined than in the dacite porphyry. Besides the two main veins small stringers have been gophered for short distances. The maximum width of the vein is 4½ feet, but in places it narrows to a few inches. Above the upper level there are old workings on the hillside, now inaccessible, from which, it is said, extremely rich oxidized ore was taken.

The gangue minerals are quartz and calcite. Much of the quartz presents a faintly mottled grayish appearance, probably due to the inclusion of minute particles of carbonaceous matter from the slate wall rock. Fragments of almost completely replaced dacite porphyry are likewise common. Calcite is less abundant than in the Gladstone ore but is present in small patches in the quartz. The proportion of calcite in the ore appears to be increasing in depth.

The sulphides in the ore, in the order of their prominence, are arsenopyrite, pyrite, galena, and sphalerite. Arsenopyrite occurs in small well-formed crystals rarely over 3 millimeters in length. Its characteristic position is close to the porphyry walls or in scattered crystals in the altered porphyry close to the vein. Arsenopyrite also occurs in small quartz stringers in the porphyry, but was not seen in the larger veins. The pyrite is also found with the arsenopyrite as an impregnation of the porphyry, but is more prominent where slate forms the wall rock. Although more prevalent in the wall rock than in the quartz, it is more general in its distribution than arsenopyrite. In the vein itself the pyrite is usually present as small specks and crystals, closely associated with sphalerite and to a less extent with galena. Galena and sphalerite are entirely confined to the vein. Galena is the more abundant of the two minerals, and though its most common position is near the walls or included fragments of slate it also occurs in small irregular patches a few millimeters in diameter in the quartz itself, entirely without relation to the walls. Sphalerite is similar to galena in its distribution. Neither mineral shows distinct crystal outlines. Altogether the sulphides, according to Mr. Musser, the superintendent, amount to about 0.75 per cent of the weight of the ore and carry $150 to the ton in gold.

Visible gold is more abundant in this ore than in the average ore of this type. In all specimens examined, in which the gold is present in sufficient size to be visible with a hand lens, it is in close association with the galena.

The oxidized ores were all mined in the early days, and no data could be obtained as to their value or the depth to which oxidation extends.

The ore of the main vein, which runs at its best about $45 a ton, is in rather irregular pay shoots that pitch steeply to the south. The best ore is commonly found where the vein is in the slate close to the porphyry contact. In the lowest level, 130 feet below the adit and about 200 feet below the point where the vein crosses the slate and porphyry contact, the ore is said to decrease in value, although it presents the same general appearance.

MILKMAID MINE (21).

The Milkmaid mine adjoins the Franklin on the east and is under the same ownership. No work has been done for several years, and the production is unknown.

The rocks in the vicinity consist of soda granite porphyry similar to that at the Franklin mine, diorite porphyry, and much-sheared slate of the Bragdon formation. Both porphyries are intrusive into the slate, but their relative ages could not be determined. The soda granite porphyry is a part of the mass exposed at the Franklin. The diorite porphyry is a dark-gray aphanitic rock. The only minerals visible under the hand lens are phenocrysts of white feldspar, some of them as much as 5 millimeters square, which are thickly scattered over the rock.

In one tunnel a vertical vein striking N. 10°–30° E. near the contact of the slate and diorite porphyry had been stoped to some extent. What ore was seen consists of quartz intergrown with a little calcite and rare pyrite. To the south is an incline shaft apparently following another vein. The dip of the incline is 44° and the direction N. 60° E. The quartz on the dump is very glassy in appearance, shows vugs with crystals two centimeters in length, and is iron stained.

WASHINGTON MINE (22).

The Washington mine (Washington Gold Mining Co., owner; Maxwell & Ketch, lessees), covers the greater part of the hill between the two forks of French Gulch. The mine was located in 1852 and is said to be the oldest in the county and one of the oldest in the State. From September, 1853, to September, 1854, its output was $53,232. At the close of 1855 the workings consisted of three levels of 522, 222, and 97 feet and three shafts of 34, 12, and 23 fathoms.[1] In 1869 there was a 22-stamp mill on the property and the production was $45,722.[2] In 1871 a production of $31,153 was reported.[3] In 1890 the total production up to that date was reported as between $500,000 and $600,000.[4] The exact total is unknown, but persons familiar with the district estimate it at one to two million dollars.

No regular work has been done for several years, but lessees have been at work more or less regularly in different parts of the property. The equipment consists of a 10-stamp mill run by water power and two vanners. There are numerous tunnels, many of which are now inaccessible, connected by raises. The workings honeycomb the hill from the creek level at about 2,000 feet to a point near the summit, at about 2,900 feet.

The lower workings are in the meta-andesite, which is overlain by slate. These rocks are cut by a great number of intrusions of soda granite porphyry and diorite porphyry, which vary from sheets a few inches in thickness to dikes and irregular masses up to 200 feet or more thick. The meta-andesite extends up as high as the sublevel 150 feet above the lower main tunnel elevation (2,400 feet). Owing

[1] Trask, J. B., Report on the geology of northern and southern California: Rept. California State Geologist, 1856.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870.

[3] Idem, 1872.

[4] Tenth Ann. Rept. California State Mineralogist, 1890.

to movement at small angles to the contact, irregular wedges of one rock penetrate the other and give the meta-andesite the appearance of an intrusion into the slate.

The intrusive porphyries in the vicinity of the veins consist of a biotite-bearing diorite porphyry that outcrops in two large sills in the southern fork of French Gulch, soda granite porphyry that forms a large mass to the south of the main (2,500-foot) tunnel, numerous small sills and dikes on the point of the ridge to the west, and diorite porphyry that outcrops near the mill about 500 feet south of the workings. The biotite-bearing diorite porphyry resembles the soda granite porphyry so common in the region, except for the lack of quartz and the more calcic nature of the feldspars. The soda granite porphyry is in every respect closely similar to that exposed in the Franklin workings and is probably a part of the same mass. The diorite porphyry shows numerous white-zoned feldspars (as much as a centimeter in length) in a dark groundmass.

Two veins have been worked on the property. One of these strikes about north and dips 60°–70° E. and appears to cut off the other, which strikes a few degrees north of east and dips at varying angles to the north. The north-south vein is a well-marked fault plane with a large amount of gouge, in which occur lenses of quartz having a maximum width of about 10 feet. The other vein pinches and swells to a considerable degree, but the ore as mined in few places was over 4 feet wide. Small stringers and veinlets branching off in every direction, have been followed in the hope of encountering rich pockets.

The ore is quartz with a small amount of sulphides. The two veins are similar, but the ore of the north-south vein may contain slightly more blende and less galena than the east-west vein. Quartz is the most abundant gangue mineral. It is white and massive, having in places a somewhat glassy appearance, and is comparatively free from the included carbonaceous matter which gives the gray color to the quartz of neighboring mines. Calcite occurs only in small specks in the quartz, and sericite was seen only under the microscope, in minute quartz veinlets which cut the pyrite.

The metallic minerals include pyrite, galena, blende, and arsenopyrite. Pyrite is by far the most prominent and is not, as in the Franklin ore, associated principally with the wall rock but is distributed throughout the ore, generally in small and rather distinct fissures in the quartz, usually not over 3 centimeters in length and 3 or 4 millimeters in width, and associated with small amounts of galena and in places with a little blende. Pyrite also occurs in small patches or individual crystals, the latter generally less than a millimeter square, and to some extent as an impregnation of the wall rock. Galena is found in small fissures associated with a larger amount of pyrite and to a less extent in small specks, about a millimeter wide, in the quartz, principally near the walls. Sphalerite follows the galena very closely but is far less in amount. Arsenopyrite was seen at only one point where soda granite porphyry had been completely silicified and impregnated with pyrite and arsenopyrite. The arsenopyrite is in very minute (0.5 millimeter or less), well-formed crystals, for the most part grouped close to fairly well-marked planes in the altered rock. Small crystals were also seen in small quartz veinlets which cut the silicified porphyry. Visible gold in the primary ore is found only in close association with the galena, and the presence of galena is looked upon as a sign of valuable ore.

The oxidized ore that was first mined was exceedingly rich and ran as high as $600 a ton. The first mining work done consisted in sluicing the rich and decomposed material on the outcrop. At present two lessees are working stringers of oxidized and partly oxidized ore on the upper part of the hill. These veinlets occur in close connection with the numerous small dikes of soda granite porphyry, and contain in places small pockets of very rich ore Where completely oxidized the ore is a white quartz with irregular reddish stains of iron oxide. Small honeycomb-like cavities 1 or 2 centimeters in length are scattered throughout the rock, representing the oxidation of the sulphides. All these cavities contain more or less iron oxide and are irregularly flecked with small leaf-like plates of gold, at the largest 3 or 4 millimeters in length.

Of the two principal veins the north-south vein was chiefly worked near the surface but was not found profitable below an elevation of 2,500 feet, and the east-west vein was principally worked below this level. On the latter vein the ore shoot appears to pitch west.

NIAGARA MINE (23).

The Niagara or Black Tom mine occupies a part of the same hill as the Washington but lies farther west. The property was located in 1857 but has not been worked for some years. The total production is estimated at somewhat under a million dollars.

The workings consist of several tunnels on both the north and south sides of the ridge. On the dumps, besides slate and conglomerate, are fragments of both diorite and soda granite porphyry, the latter in part more or less completely silicified, leaving phenocrysts of glassy quartz in a chalcedonic groundmass. So far as can be judged from the accessible lower workings, diorite porphyry forms the larger portion of the mass. Fine-grained quartz-augite diorite outcrops on the road near the lower tunnel, and a few pieces were found on the lowest of the several tunnel dumps.

Such ore as was seen was quartz, without any calcite. The usual sulphides are present in small amounts. Pyrite is most widely distributed, as it is found in the quartz, in the small stringers in the slate, and disseminated in minute crystals in the porphyry. Most commonly, however, it is in close association with the galena, here and there completely surrounding small fragments of that mineral. Arsenopyrite is in places in small crystals in the vein but is more commonly scattered through the altered porphyry in the wall. Galena and sphalerite are most abundant near the slate wall rock and include fragments of slate.

SUMMIT MINE (24).

The Summit mine (Joseph Porter and the Wheeler estate, owners; Allen & Alexson, lessees) is near the top of a spur running eastward from the county divide, about midway between the Brunswick and Niagara mines. Since 1907 the lessees have taken out about $30,000. The estimated total production is about $200,000.

A dike of soda granite porphyry from 25 to 40 feet wide cuts the slates and is itself crossed by two veins. The porphyry is rather finer grained than other rocks of this type and shows prominent biotite and feldspar phenocrysts, 1 to 2 millimeters in diameter, but no quartz.

The veins have been developed by three adit levels at vertical intervals of about 40 feet. The ore is quartz with a very subordinate amount of calcite and, near the walls, specks of metallic sulphides, pyrite, galena, sphalerite, and arsenopyrite, together with gold. For the most part the quartz is similar to that of other veins in the vicinity, massive and in part of a grayish tinge, but in places containing vugs 6 or 8 inches across. The oxidized ore shows staining by manganese as well as iron oxide. Of the sulphides, sphalerite is perhaps the most common and occurs in small crystals with galena and pyrite in the quartz at distances of less than a quarter of an inch from the wall. Arsenopyrite is in its usual position in the porphyry, close to the quartz, and in one specimen occurs in small streaks in the quartz near the wall. Visible gold in the vein itself was seen only in association with the arsenopyrite rather than around its usual nucleus of galena. In the large vugs gold is seen on many of the quartz crystals themselves, and in one specimen small flakes are inclosed in a large crystal, though possibly along a small fissure in the crystal.

Although one of the veins has been followed for as much as 300 feet, very little good ore has been encountered outside of the porphyry dike. Here ore running as high as $150 a ton is found in small ore shoots 20 feet or less in length along the drift, although on the second level the western vein showed workable ore all the way across the dike. Outside of the dike only a few small ore shoots have been worked. The richest ore mined, according to Mr. Alexson, was one 3-ton lot that milled $423 a ton.

The ore must be carted from the mine to the Washington mill on French Gulch, and hence mining is comparatively expensive.

BRUNSWICK MINE (25).

The Brunswick mine (Brunswick Mining Co., of French Gulch, owner; H. D. Lacey, manager) is 2 miles south of the group of mines in French Gulch, on a steep ridge between Sawpit Gulch and Summit Gulch. The elevation of the tunnel is slightly less than 4,000 feet.

The mine was first located in 1879 and has been under its present ownership since 1906. The total production has been about $70,000, of which $45,000 was produced since 1906. There is a 10-stamp mill on the property, but it is not in operation, as the company is confining its attention to development work. In July, 1912, two men were employed.

The accessible workings consist of a tunnel that cuts entirely through the ridge and a drift along the vein. It is planned to prospect the vein at depth by a crosscut from the north side of the ridge at an elevation of 3,300 feet. The Bragdon formation is here less distorted than is common in the neighborhood of the veins and consists largely of black slate with a few conglomerate beds.

The only intrusive is a dike of augite-bearing diorite porphyry over 100 feet in width which strikes nearly east and west, though with a rather irregular contact, and dips about 60° N. The rock resembles that exposed on the Washington and Milkmaid properties, consisting of large white feldspar crystals in a gray groundmass, but the groundmass shows many minute augite prisms.

The ore lies entirely within the porphyry at a distance of 1 to 10 feet from the northern contact and consists of small lenses of quartz and rarely calcite in a narrow crushed zone. To a large extent the ore is oxidized and the white glassy quartz shows honeycombed cavities formed by the leaching out of pyrite and possibly also of calcite. These cavities, and the quartz as well, are deeply stained with iron oxide and also contain small black specks and streaks of manganese oxide. The only metallic mineral present is pyrite.

Not enough work has yet been done to indicate the size or inclination of the ore shoot. According to Mr. Lacey, the best ore so far found runs about $10 a ton.

ACCIDENT MINE (26).

The Accident or Sybil mine was idle in July, 1912. It lies at the north edge of the complex of dikes which marks the position of the group of mines near the head of French Gulch. Soda granite porphyry similar to that of the Franklin and diorite porphyry similar to the Brunswick dike cut the slate. The ore for the most part lies in the diorite porphyry near the contact of the slate, but in places the workings follow the contact itself, which here strikes about N. 80° W. and dips about 50° N.

The ore consists of blue-gray quartz with patches and streaks of white calcite, the latter sometimes as much as half an inch in width. The quartz has a mottled gray color, but the calcite is milky white and cut by veinlets of quartz and arsenopyrite 1 millimeter wide. There is the usual association of metallic minerals—arsenopyrite, pyrite, galena, and blende. Arsenopyrite is probably the most common. Its characteristic positions are as a band about a millimeter wide of very minute crystals bordering the calcite and in still smaller veinlets cutting the calcite, and in larger crystals (3 millimeters or less) scattered through the altered porphyry wall rock. Rarely small crystals appear in the quartz. Pyrite occurs commonly in irregular patches of crystals in the quartz, and to a less extent is present in millimeter-sized crystals in the altered porphyry near the vein. Galena is scattered through the quartz in patches and is commonest near the walls. Sphalerite is usually close to galena, but is less in amount and tends to be more generally scattered through the vein than the galena. Gold, wherever in plates large enough to be visible, is always close to the small patches of galena. Except for the small quartz and arsenopyrite fissures traversing the calcite, the sulphides occur only in the quartz or wall rock.

THREE SISTERS MINE.

The Three Sisters mine has evidently been abandoned for several years. The vein worked must be near a contact of soda granite porphyry with the slate, as both rocks are present on the dump. The ore is a white quartz with small veinlets of calcite that have weathered to a dark-brown color, implying the presence of manganese. Arsenopyrite and pyrite are the two metallic minerals present. The arsenopyrite is most closely associated with the altered porphyry, and the pyrite with the slate.

HIGHLAND MINE.

The Highland mine, at the head of Dutch Gulch, has a recorded production of $4,322 for 1869 [1] and $9,650 for 1871.[2] It has been idle for years, however, and was not visited.

SHIRTTAIL MINE.

The Shirttail mine, in the meta-andesite area on Drunken Gulch, was idle in July, 1912, and was not visited.

DEADWOOD DISTRICT.

LOCATION AND PRODUCTION.

The Deadwood district is separated from the French Gulch district, to the east, only by the county line. For all practical purposes it is a part of the same district. The geologic conditions are identical.

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[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870.

[2] Idem, 1872.

Dikes of porphyry of varying texture and composition cut the slates of the Bragdon formation and the veins are found in close proximity to the intrusive rocks.

The production of the district for 1909[1] was 2,415 tons, valued at $31,094, and for 1910[2] 2,723 tons, valued at $49,158. This gives an average tenor of $17 to $18 a ton.

Only one of the several mines of the district, the Brown Bear, was visited. Others are the Blue Jay, Lappin, Vermont, and Goodyear & Richards.

BROWN BEAR MINE (27).

The Brown Bear mine (Thomas McDonald, part owner; Barney McDonald, superintendent) is in the village of Deadwood, on the north side of Deadwood Gulch. The property was discovered in 1875 and has been worked ever since. The present Brown Bear property is a consolidation of several mines and taken as whole it has undoubtedly been the largest producer in the quadrangle; its total production is estimated by Thomas McDonald as between $7,000,000 and $10,000,000.

The mine has been opened by crosscut tunnels at depths of 340, 395, 420, 520, 640, 725, and 1,080 feet below the outcrop, besides several smaller old workings between the outcrop and the upper level. As two principal veins have been developed to a maximum distance of 1,400 feet, besides drifts on minor veins, and the longest crosscut is about 2,300 feet, it follows that there are several miles of workings. In the short time available it was impossible to make more than a very hasty examination of a comparatively small part of the mine.

There is a 10-stamp mill with two Wilfley tables, capable of handling about 20 tons a shift. In September, 1912, the force consisted of four miners and seven lessees.

The country rock is slate of the Bragdon formation, cut by a large number of irregular intrusions that represent different types, including both diorite and soda granite porphyry.

There is almost everywhere evidence of motion along the slate and porphyry contacts. At only one place was an intrusive contact without gouge seen. The veins lie for the most part in slate but also cut the porphyry. Besides numerous small veins and stringers two principal veins have been worked; these are parallel and have an average strike of N. 80° E. The northern vein, the Monte Cristo, dips steeply to the north; the Last Chance, 200 feet south of the Monte Cristo, dips south at angles between 60° and 80°. The width is as a rule not over 2 feet, more commonly about 6 inches, but stopes have been taken out to a width as great as 22 feet. Two small veins

[1] Mineral Resources U. S. for 1909, pt. 1, U. S. Geol. Survey, 1910.
[2] Idem for 1910.

developed to some extent on the lower levels have strikes of N. 20° W. and N. 50° W.

The ore shoots on the Last Chance vein appear to pitch at a rather flat angle to the east. The veins show slipping along both walls and there is always some gouge present, locally as much as 3 inches. The gouge carries fragments of quartz and a little gold. It is very rare that the ore is frozen to the wall.

Quartz is the principal gangue mineral. Much of it has a cloudy blue-gray color and in many places it is banded, owing to inclusions of slate parallel to the walls. Calcite is comparatively rare in the ore and is more commonly seen in the small irregular stringers in the slate and porphyry near the veins. Manganese oxide is noticeable in the surface quartz. The sulphides consist of pyrite, galena, sphalerite, and arsenopyrite. The concentrates carry about $100 in gold to the ton but form a very small percentage of the ore. Pyrite is the most common sulphide and is found both in the vein and impregnating the slate and porphyry walls. Small stringers of pyrite cut the slates near the veins, and the joint planes of the slate and porphyry are in places heavily pyritized. Galena and sphalerite show no tendency to migrate into the country rock and are found in the vein, their presence generally indicating rich ore. Although they are rare in the ore as a whole, in a few places the vein is almost entirely made up of these two minerals and pyrite. Arsenopyrite is almost exclusively confined to the altered porphyry, where it occurs both in crystals scattered through the rock and in extremely minute crystals along joint planes. Visible gold is common. All the gold seen was in the quartz close to either an included fragment of slate or a patch of galena. Its fineness is about 0.840. The best ore of the present workings runs over $100 a ton and the general run of ore as stoped is between $20 and $50.

DOG CREEK DISTRICT.

The mines of the Dog Creek district are all within the areas of meta-andesite which lie near the heads of Dog Creek and Stacy Creek. On Dog Creek, just east of the quadrangle, is a mass of intrusive alaskite porphyry. Many dikes of soda granite porphyry cut the meta-andesite and the overlying slates of the Bragdon formation.

DELTA MINE (28).

The Delta group of 30 claims (Delta Consolidated Mining Co., owner; S. D. Furber, manager) lies near the head of Dog Creek, about a mile northeast of the Toll House. The recorded production has been $32,000, which does not include the earlier arrastre workings. A narrow-gage railroad was built from the mine to the town of Delta over which a small amount of ore was shipped to the smelter.

The country rock of the veins is meta-andesite, which is cut by numerous dikes of feldspathic dacite porphyry and a few dikes of alaskite. The slates cap the hills above but are not reached by the veins. A short distance east of the quadrangle is a large mass of intrusive alaskite porphyry.

Numerous small veins have been developed for short distances on different claims. These vary from 1 to 2 feet in width and strike between east and N. 70° E. The dips are vertical or steep to the north. Branching is common and the veins tend to taper out within short distances. The workable ore is in irregular shoots and carries between $8 and $10 a ton in gold.

The usual ore is quartz, generally dark blue-gray in color except where oxidized, with a small amount of calcite and scattered specks of barite. The principal sulphide is pyrite, but small amounts of galena and blende are also present in the unoxidized ore. One of the veins contains small patches of arsenopyrite crystals that are said to have an extremely high gold content. In certain of the veins chalcopyrite is prominent. The sulphides, so far as seen, are associated only with the quartz and are never found in the calcite. Pyrite, however, is present in the altered wall rock as well. Usually the other sulphides occur in small lines cutting the quartz or in irregular patches. Gold visible to the naked eye is seen only in the oxidized ore, where it occurs in manganese-stained cavities in the quartz or with streaks of iron oxide.

Recently copper deposits have been discovered on the property. The ore is supposed to be similar to that of the Shasta copper belt in that it is a replacement of an alaskite dike by copper sulphides. Where seen, the ore consisted of specks of pyrite and chalcopyrite in a gangue of grayish quartz and calcite. In several places there are outcrops of a cellular limonitic gossan that carries a small amount of gold. Where prospected by a tunnel 100 feet below this gossan the ore is a much-altered rock, possibly originally alaskite porphyry, carrying pyrite and barite. It assays about $2 to $3 a ton in gold and is supposed to carry copper as well.

COPPER SNAKE PROSPECT.

The Copper Snake prospect (W. B. Glenn, owner), on Stacey Creek about 2 miles southwest of the Toll House, consists of three small prospect tunnels on a somewhat faulted quartz vein. Not enough work has been done to determine the size, though it appears to be of greater width than the average vein of this region. The vein lies between walls of meta-andesite and soda granite porphyry.

The ore is a mottled grayish quartz carrying irregular masses of chalcopyrite and a subordinate amount of pyrite. A small amount of calcite is found near the footwall. Free gold, some of it in valuable pockets, has been found near the surface, particularly in connection with streaks and patches of manganese oxide. Some of the sulphide ore, according to Mr. Glenn, carried 0.6 ounce of gold and 4 ounces of silver to the ton and 15 per cent of copper.

STACEY MINE (29).

The Stacey mine (J. C. Brown, owner) adjoins the Copper Snake on the south. The total production has been about $45,000, entirely from small pockets.

The country rock of the vein is meta-andesite, much altered in the immediate vicinity of the vein. The lower crosscut shows a flat-lying mass of feldspathic soda granite porphyry with irregular boundaries.

The vein is from 1 to 8 feet wide and strikes about N. 15° W. At its northern limit it is cut off by a vertical fault with a strike of N. 30° E. The ground to the northeast is now being explored in the hope of picking up the continuation of the vein.

The ore is chiefly quartz, which is highly manganiferous and accompanied by small amount of manganiferous calcite. The pockets so far found have been in close association with patches or streaks of manganese oxide. No pyrite or prominent iron oxide staining was seen in the ore.

MINERSVILLE DISTRICT.

With the Minersville district is included the country along Trinity River between Trinity Center and Papoose Creek. Numerous irregular folds have brought the meta-andesite to the erosion level reached by Trinity River and its branches, and there are many small patches of meta-andesite whose contacts with the slate have furnished rich pocket deposits. The contacts in the vicinity of Minersville have been particularly productive, and besides supplying the pockets have furnished much gold to the placers of this neighborhood.

FIVE PINES MINE (30).

The Five Pines mine (Five Pines Mining Co., owner; Lester Van Ness, manager) is situated on the northeast side of Van Ness Creek about 1½ miles above its mouth. The property was discovered in 1896 by H. J. Van Ness and has produced a total of $275,000. The equipment consists of a two-stamp mill, but the gold is so coarse that, according to an estimate by Mr. Van Ness, 80 per cent of the total product has been recovered by hand mortar and pan.

The ore lies along a contact of meta-andesite with the overlying slate and sandstone. The meta-andesite occurs as a low dome, the center of which has been cut through by Van Ness Creek. The contact pitches gently to the northeast and southwest and much more steeply to the northwest and southeast, giving the area a roughly elliptical shape with axes about one-half and one-quarter of a mile in length. The nearest intrusive rock is a dike of fine-grained alaskite porphyry which crosses Van Ness Creek a mile southwest of the end of the andesite area.

The dip of the slates and sandstones is most irregular and variable but in general is away from the meta-andesite. There has been motion along the contact of the slates and meta-andesite, as is shown by the crushing of the slates and the gouge along the contact.

The ore is found in a series of pockets which lie along the slate and meta-andesite contact on the northwest and southeast limbs of the anticline, but not at the crest. The mine includes two distinct deposits; the determining feature of each is the presence of a vein of very low grade manganiferous quartz which cuts the slate and underlying meta-andesite. Associated with the vein are many small quartz stringers.

The gold occurs in calcite along the contact of the slate and meta-andesite. Although the calcite, somewhat mixed with quartz, is nearly continuous along the contact and carries everywhere small amounts of gold, the principal returns are obtained from small but very rich pockets in the calcite. The best of these pockets yielded $45,000 in a vertical distance of 44 feet, and other pockets yielding $15,000 and $10,000 have been mined. All these pockets have been found close to the contact of the slate and meta-andesite, but the ore is everywhere much mixed with slate. The low-grade quartz vein and the numerous small stringers of quartz determine the position of the pockets, as all so far found are at or near points where the quartz stringers or vein meet the quartz at the slate and meta-andesite contact. Some ore is found in the meta-andesite, but it is nowhere farther than 4 feet from the slate. More rarely small pockets have been found in the slate where small stringers of calcite cross the slate and sandstones.

The gangue minerals are calcite, quartz, and barite, the first by far the most abundant, particularly in connection with the rich pockets. In a few of the specimens collected it shows a distinct pinkish tinge, presumably due to manganese. Quartz is intimately mixed with the calcite. The surface ore is honeycombed from the solution of the calcite and is in places stained by manganese oxide. Barite was seen in minute tabular crystals in the pink calcite.

Sulphides are rather rare and include only pyrite and arsenopyrite. Both are said to be auriferous, but owing to their low tenor they are not saved. Arsenopyrite is the more common of the two and occurs in minute crystals along shear planes of the black slate close to the calcite, and more rarely in small radial clusters in the calcite itself. Pyrite was seen chiefly in the slate but also in the calcite close to the slate.

Visible gold is not present in the quartz but occurs in the calcite or between the calcite and black slate. In the calcite it appears to be deposited along the cleavage planes and was not seen far from the slate. A hand specimen of ore from this mine on exhibition in the rooms of the State Mining Bureau at San Francisco shows calcite in which the cleavage planes are outlined with gold, the planes being so close together as to give the effect of as great a volume of gold as of calcite in the specimen.

The main adit is 77 feet above the level of Van Ness Creek and 225 feet below the highest outcrop. The contact has been followed down from the adit level for a distance of 225 feet, or to about 43 feet below the stream. A level has been opened at 125 feet down the incline, or about 10 feet below the stream, and pockets have been found in the ground between this and the adit level. No work has yet been done on the lower level, so that it is not certain whether the pockets actually extend below the present water level.

According to Mr. Van Ness all the rich pockets were along water-courses, and the work so far done shows that in deposits of this type gold may be looked for at least as deep as the water level.

MOUNTAIN VIEW PROSPECT (31).

The Mountain View prospect (Fred R. Geddings, owner) consists of several irregular tunnels on the ridge south of Little Bear Gulch. The tunnels are in meta-andesite below the slate; only the upper one follows the contact. Small veins of white quartz, in places deeply stained with manganese oxide, have been followed and stoped to some extent. The largest of these veins is about a foot in width. When crushed and panned the quartz shows free gold in fine colors. The ore has been worked in an arrastre on Little Bear Creek, but the total production is unknown.

FAIRVIEW MINE (32).

The Fairview mine (Fairview Mining Co., owner; W. Waldo, lessee) is on the east bank of Trinity River 2 miles southeast of Minersville post office. The ground was located by Mr. Waldo in 1897 and worked by the company from 1901 to 1908 and by the present lessee since 1910. Mr. Waldo estimates that the total production has been about $200,000. A 40-stamp mill was built during the period of company operation but was never run at its full capacity. The mine is opened by tunnels at four levels, only the lowest of which is now accessible.

The vein as far as worked is entirely in slate and has a strike ranging from west to northwest. The dip is 50°–80° N. The contact of slate and meta-andesite dips about 45° E. It is not known whether the vein pinches out or is faulted at the contact, but from the facts that there has been movement along the contact, as may be seen on the accessible adit level, and that none of the stopes reach the meta-andesite, it is believed that the vein is most probably cut off by a fault. At the third level the vein splits, and in the present workings between the third and fourth levels one branch is about 40 feet to the south. The vein is irregular in outline and its maximum width is about 20 feet.

The ore shoots so far stoped pitch at a low angle (about 20°) to the east and consist of small bands about a foot wide close to the slate walls. The ore as mined runs from $7 to $30 a ton. Occasionally very rich pieces of "specimen ore" are found at the contact of the quartz with the slate. The quartz is much mixed with slate fragments. A few manganese stains were seen. There is a small amount of pyrite present but no other sulphides. The pyrite is said to be practically barren.

DEDRICK DISTRICT.

The country rock of the mines of the Dedrick district near the village of Dedrick, in the northwestern part of the quadrangle, is hornblende schist, which here forms a broad belt, cut by masses of quartz diorite and dikes of porphyritic rocks. The high relief allows much of the mine development by tunnels. The district was formerly a much larger producer than at present, but renewed operations on two of the mines promise to give it a more important place in the near future.

GLOBE (33), BAILEY (34), AND CHLORIDE MINES.

The Globe, Bailey, and Chloride mines (Globe Consolidated Mining Co., owner; C. E. Lamb, manager), are situated on the hill northwest of Dedrick and about 4 miles northwest from the summit of Weaver Bally. Only the Globe (33) is now in operation. The present equipment is a small 10-stamp mill on the east side of the mountain, at an elevation of about 6,500 feet. Power is supplied from the company's plant above Dedrick. The principal difficulty is shortage of water during the summer and heavy snows throughout the winter, which prevent the working of the mine between November and April.

The vein lies in a belt of hornblende schist between two areas of granodiorite. The schist is composed of hornblende with a minor amount of quartz. Near the Globe mine the strike of the schistose banding is N. 55° W. and the dip 60° SW., practically the same as for the whole hill. In a few places small pegmatitic lenses follow the trend of the schistosity. Near the Globe vein a small dike of diorite porphyry cuts the schist and near the Chloride workings are dikes of alaskite porphyry and soda granite porphyry.

The Globe vein is opened by tunnels at elevations of 6,310 and 6,175 feet. The upper tunnel is the longest and has been driven a distance of 1,700 feet, nearly through the hill.

The vein consists of a series of quartz lenses in a zone of much-sheared schist, striking S. 55°–70° W. on an average dip of 60° SE. The intense shearing and consequent drag of the schists make it appear as if the ore lenses were parallel to the schistosity, whereas in reality the strike is nearly at right angles to it. The lenses have an average length of about 200 feet, a maximum of 400 feet, and a width of 8 or 10 feet. The widest portion of the largest lens is 36 feet wide. Parallel lenses in both footwall and hanging wall have been crosscut but not yet developed. The longest interval without quartz between any two lenses is about 50 feet, though it is rare that such an interval exceeds 20 feet. Where the quartz pinches out a well-marked zone of talcose material about a foot wide leads to the next lens. Under the microscope this material is seen to be an aggregate of chlorite, sericitized feldspar, calcite, and a little quartz and pyrite.

The ore is white quartz, much shattered and friable and generally stained with iron and manganese oxides. Another nonmetallic mineral is albite feldspar, which, however, is extremely rare. It occurs only in contact with small fragments of schist included in the quartz, and is much kaolinized. These included fragments of schist are sharp and angular and there is no evidence of replacement. Calcite is present in small amount.

Pyrite is the only sulphide present and is found in irregular patches, generally near the hanging wall. It is auriferous and is saved, though no concentrates have yet been shipped. The gold of this mine is more finely divided than usual and is not in large enough pieces to be visible to the naked eye. About $14 a ton is recovered on the plates. The ore shoots within the lenses are irregular, but the best ore is generally found along the hanging wall. The presence of spots and streaks of manganese oxide is also regarded as a favorable indication.

The Bailey mine (34) lies about a mile to the southeast of the Globe, on the west side of the divide. The upper workings are caved, but a tunnel is being run 60 feet below the lowest of these to crosscut the Globe vein at an elevation of about 5,720 feet. In

September, 1912, this tunnel had a length of 1,100 feet and was expected to reach the Globe ore at about 200 feet farther. At 600 feet from the mouth a 5-foot vein of white quartz carrying a little calcite was crossed. This appears to be the same as that of the upper workings.

The workings of the Chloride mine were entirely caved, but so far as could be seen from the dump and ore bin the ore and country rock are similar to those of the Bailey and Globe.

The company is now erecting a modern stamp mill and cyanide plant north of Dedrick. When the Bailey tunnel reaches the Globe vein it will become the working level of the mine and winter work will then be possible.

CRAIG MINE (35).

The Craig mine (Craig Mining Co., owner; C. E. Lamb, manager) is about 2 miles southeast of Dedrick and a mile west of the border of the quadrangle. It is opened by tunnels 70 feet apart, the longest of which is about 1,100 feet long.

The vein is entirely within the hornblende schist, which here strikes N. 55° W. and dips 70°–85° S. About half a mile to the west is an intrusion of dacite porphyry. The granodiorite lies about a mile to the east.

As in the Globe mine, the vein is a series of quartz lenses and cuts the schist at almost a right angle. The quartz, however, nowhere entirely pinches out, as in the Globe, but varies from 3 inches to 6 feet in width. The gangue consists of quartz with a very subordinate amount of calcite. The quartz is white and dense in the wider parts of the vein; elsewhere it is banded with altered and partly replaced schist and in places is a cloudy gray in color. Calcite was seen only in small patches close to the walls.

Pyrite is the principal sulphide mineral and is much more plentiful than in the Globe. As a rule, it is close to the walls and in the partly replaced schist included in the vein. Much pyrite is scattered through the white quartz, however, some of it in large crystals. These large crystals, some of which are over an inch square, are broken and veined by quartz. A small amount of chalcopyrite is scattered through the quartz with the pyrite.

It is said that the ore averages above $20 a ton but is extremely streaky and irregular. Visible gold is rarely seen.

A 10-stamp mill and cyanide plant are being erected on the property.

SUMMARY.

During late Jurassic or early Cretaceous time the Paleozoic rocks of the Weaverville quadrangle were intruded by masses and dikes of igneous rock. Among the most important of these is the batholith of quartz diorite and granodiorite, which was followed by a series of silicic and basic dikes. The period of fissuring and ore deposition followed the intrusion of the dike rocks, and the veins appear to be genetically connected with certain types of dike rock, particularly the soda granite porphyry.

Native gold is the principal valuable mineral of the veins. The sulphides are auriferous, but their total volume is too small to form an important part of the ores.

The fissure veins in or near the slate of the Bragdon formation are usually associated with dikes or masses of soda granite porphyry. The vein filling is made up of quartz and calcite, with small amounts of galena, sphalerite and arsenopyrite, as well as free gold, which is locally present in flakes large enough to be readily visible. The veins are persistent both in dip and strike and below a shallow zone of surface enrichment show no marked change in character with depth. The rich surface zone is probably due in great part to the solution of the calcite, which has left the quartz correspondingly enriched, and to a less extent to solution and redeposition of the gold.

Comparatively few of the veins in the quartz diorite and alaskite porphyry were studied. In these calcite is less common and pyrite is almost the only metallic mineral present.

The pocket deposits are found almost entirely along faulted contacts of the slate and meta-andesite. It is believed that these deposits are of surficial origin, and that the gold originally present in small quartz veins or in pyrite has been taken into solution by the acid surface waters through the agency of manganese oxide and precipitated by the carbon of the slates, and that the process of pocket formation was facilitated by the neutralization of the descending auriferous waters through the solution of calcite.

MINERAL RESOURCES OF THE INYO AND WHITE MOUNTAINS, CALIFORNIA.

By Adolph Knopf.

INTRODUCTION.

The first chain of mountains east of the southern part of the Sierra Nevada is known as the White Mountain Range; the southern portion of it is termed the Inyo Mountains and the northern portion the White Mountains. Since 1860 mining has been in progress in this region, but the period from 1869 to 1877 comprises the years of greatest activity, for it was then that the mines of Cerro Gordo, in the Inyo Mountains, were yielding the great output of base bullion that made this locality the only notable producer of silver-lead ore in the State of California. Gold ores have also been important, and recently zinc carbonate ore has been developed on a commercial scale.

The previous knowledge of the geology and ore deposits of the range has been brought together by Spurr from various scattered sources of information,[1] and W. T. Lee, on the basis of his own work, has briefly described the geology of Owens Valley and the origin of the valley with reference to the confining mountain ranges.[2]

The present report is based on field work in progress from July 6 to October 18, 1912, during which time that portion of the White and Inyo mountains lying within the Bishop, Mount Whitney, and Ballarat quadrangles was geologically surveyed, special attention being given to the phenomena of mineralization and to the mining districts contained in the area. During this work the writer was efficiently assisted by Mr. Edwin Kirk, who devoted special attention to the stratigraphy and paleontology of the range.

The following pages present a short summary of the general geology of the range, followed by a description of the metalliferous mineral resources which is as detailed as the present mining developments warrant. The region with which this report is concerned covers essentially the southern 75 miles of the range.

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[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California, 2d ed.: Bull. U. S. Geol. Survey No. 208, 1905, pp. 206–212.

[2] Lee, W. T., Geology and water resources of Owens Valley, California: Water-Supply Paper U. S. Geol. Survey No. 181, 1906, 28 pp.

GEOGRAPHY.

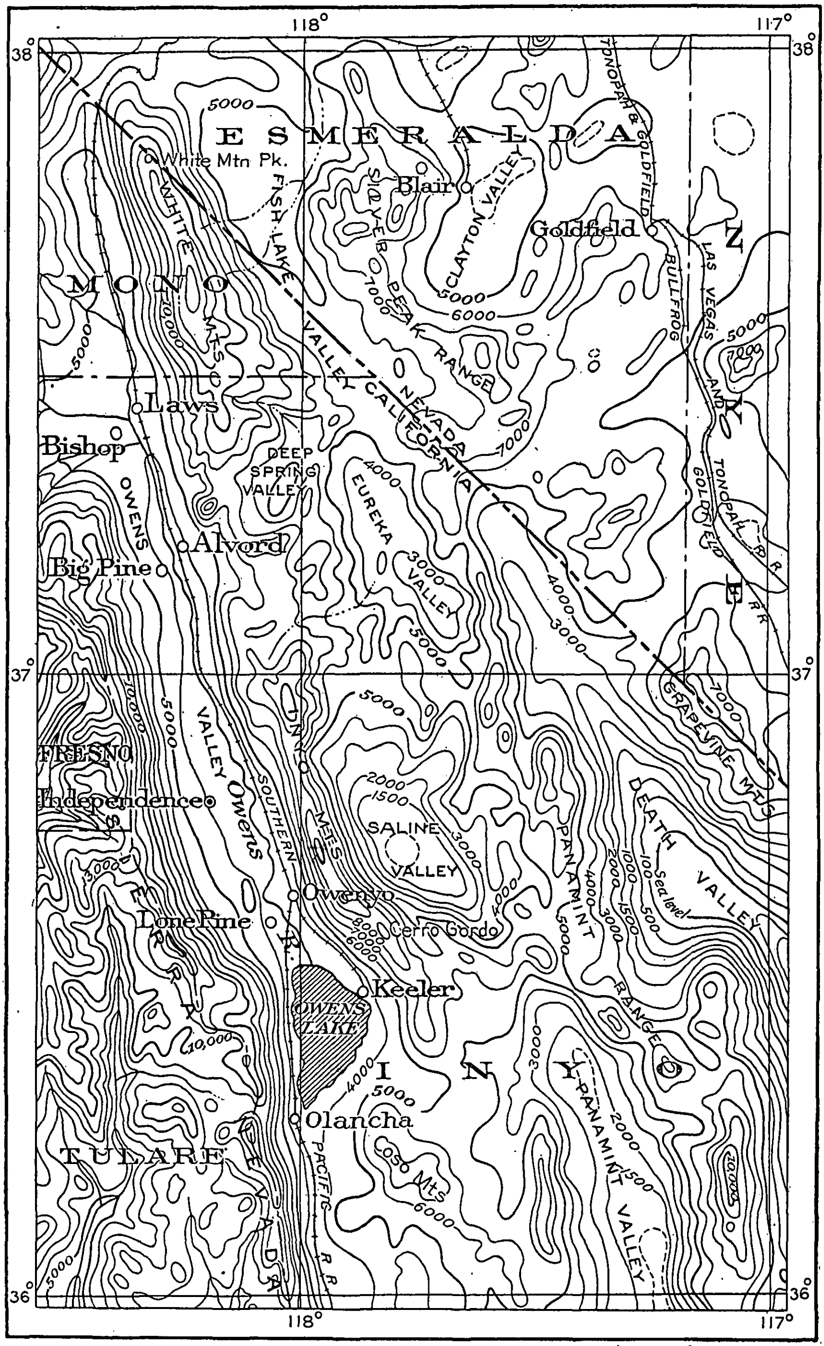
The Inyo and White mountains form the east wall of Owens Valley in Inyo County, Cal. (See fig. 5.) Together they constitute a single continuous chain, 110 miles long, the Inyo Mountains forming the southern portion, and the White Mountains the northern portion. The line of demarkation has usually been placed along the Saline Valley road, which crosses the range east of Big Pine. The arbitrary character of this division was recognized by J. D. Whitney,[1] and his opinion has been concurred in by all subsequent observers. Local usage has tended in recent years to sanction the employment of "White Mountains" as a name for the entire range, although the extreme southern portion is by preference still known as the Inyo Range.

The range trends northwest and southeast; on the south it is separated from the Coso Mountains by a broad depression and on the north it terminates in White Mountain, whose white granite scarp is a prominent landmark visible for many miles. The average elevation of the range is 10,000 feet. Its western face slopes off abruptly toward Owens Valley, forming a scarp which is but little less pronounced than that of the Sierra Nevada, on the west side of the valley. The western border of the range is thus determined by the floor of Owens Valley, and is as a whole remarkably straight. The eastern border is not so sharply marked, and the boundary on this side is somewhat indefinite. Along the northern portion of the range Fish Lake Valley clearly determines the eastern limit, but between this valley and Saline Valley there is an irregular mountainous area not clearly separated from the White Mountains on the west or from the ranges on the east. Along the southern portion the deep elliptical depression known as Saline Valley, whose floor lies 2,500 feet lower than that of Owens Valley, sharply separates the Inyo Range from the Ubehebe Range to the east. The flank of the Inyo Range is here exceedingly steep and rugged, being comparable with the great escarpment of the high Sierra.

Owens Valley, separating the White Mountain Range from the Sierra Nevada on the west, is long and narrow. Its floor ranges from 2 to 8 miles in width, and the distance from crest to crest of the confining mountain chains ranges from 40 miles at the north end to 25 miles at Owens Lake near the south end, the minimum being 15 miles between Bishop and Big Pine.[2] The elevation of the floor of the valley decreases from about 8,000 feet above sea level at the north end to 3,600 feet at Keeler, on Owens Lake, the lowest point in the valley.

[1] Geol. Survey California, vol. 1, 1865, p. 456.

[2] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: Water-Supply Paper U. S. Geol. Survey No. 294, 1912, p. 9.



10 0 10 20 30 40 MILES

Contour interval 1,000 feet
Intermediate contours below 2000 feet altitude

FIGURE 5.—Map of White Mountain Range, Cal., and adjoining territory.

TRANSPORTATION AND MINING CONDITIONS.

The Nevada & California Railroad, a narrow-gage line, formerly the Carson & Colorado but now a part of the Southern Pacific system, traverses Owens Valley along the entire front of the White Mountain Range; it connects with the Tonopah branch at Mina, Nev., and its southern terminus in Owens Valley is Keeler. A broad-gage branch of the Southern Pacific has in recent years been built northward into the valley from Mohave, primarily to aid in the construction of the Los Angeles Aqueduct, and connects with the narrow-gage line at Owenyo. Mines situated on the western flank of the range are therefore favored by proximity to railroad transportation facilities. On account of the ruggedness of the mountains, roads are difficult to construct, and the few that have been made are characterized by excessive grades—a notable example being that to the Cerro Gordo mine, in which a rise of 4,500 feet is accomplished in 8 miles. Pack trails furnish the only feasible means of access to many mines and prospects, and in former days, before the rich surface ores had been exhausted, ores were commonly packed by mules to arrastres and mills situated at water, or to the valley for shipment to smelters. This is occasionally attempted at present.

Two roads cross the range, both of which start from Big Pine, in Owens Valley. One goes to Deep Spring Valley, the distance being 28 miles; the other goes to Saline Valley, 65 miles distant, and crosses three divides, the highest at an altitude of 7,500 feet. In addition to the handicap imposed on the mining industry by the difficulties of transportation, there is a scarcity of water, fuel, and forage. In places above 7,000 feet in altitude piñon is fairly abundant, but it is usually expensive to get out.

A favorable factor, especially for mines situated on the west flank of the range, is the abundant supply of hydroelectric power which is being developed on the west side of Owens Valley. Three companies are in the field. The transmission line of the Nevada-California Power Co., supplying power to Goldfield, Nev., crosses the White Mountains by way of Silver Canyon and Wyman Creek.

GENERAL GEOLOGY.

SUMMARY STATEMENT.

The White Mountain Range is built up of a thick series of sedimentary rocks, including bedded andesitic lavas, all of which are intruded by large masses of granite.

Sedimentary and igneous rocks occur in nearly equal volume and essentially form the bulk of the mountains. Locally, however, as on the west flank of the range, there are lake beds of early Pleistocene or Pliocene age, and northwest of Deep Spring Valley and at the south end of the range, southeast of Keeler, basalt sheets attain considerable prominence.

The pre-Pliocene sedimentary formations range in age from Lower Cambrian to Triassic. They are composed largely of limestone, sandstone, and shale; limestones predominate, and, because limestones of like appearance recur in the successive formations, it is difficult to discriminate the formations, and reliance must be placed mainly on the evidence of their fossil contents. In mapping the sedimentary rocks five broad subdivisions were employed—Cambrian, Ordovician, Devonian, Carboniferous, and Triassic.

The rocks are faulted and greatly folded—in places overturned—and are much metamorphosed by extensive intrusions; consequently the stratigraphic relations as a rule are obscure. The volcanic rocks, already referred to as making up part of the stratigraphic sequence, form a prominent belt along the west flank of the southern part of the range. They are of Triassic age.

The intrusive igneous rocks are predominantly of granite character, ranging from diorite to granite. Hornblende-rich varieties verging toward hornblendite are found in the precipitous slopes of the range southeast of New York Butte. Dikes of diorite porphyry are of common occurrence in the sedimentary rocks surrounding the granitic masses; and in the foothills east of Keeler dikes of dense-grained siliceous rock (felsite) are common, generally lying parallel to the stratification of the inclosing rocks.

SEDIMENTARY ROCKS.

CAMBRIAN SYSTEM.

The oldest rocks of the region are limestones, dolomites, quartzitic sandstones, and slaty shales of Lower Cambrian age. They are present principally in the White Mountains and extend southward along the east flank of the Inyo Mountains as far as Waucoba Mountain.

The stratigraphic column, determined by piecing together a number of incomplete sections, is, according to Edwin Kirk, as follows:

Section of Lower Cambrian rocks in White Mountain Range.

	Feet.
Arenaceous limestones and slates	1,300
Upper sandstone series	2,500
Coral limestone series	2,600
Lower sandstone series	3,000
Massive white limestone	2,000
	11,400

The massive white limestone is a notable member of the Cambrian section. It is best shown on Wyman Creek, where it is transsected by the stream gorge, which exposes a belt 4,100 feet wide, or approximately 2,000 feet thick. The basal member is a bluish dolomite marble carrying obscure circular fossil remains. The subjacent rocks, which are conformably below the marble, consist of alternating limestones and slates, highly folded and contorted and therefore not susceptible of measurement. The estimate of 11,400 feet as the thickness of the Cambrian rocks is for this reason regarded as a minimum.

The rocks overlying the massive limestone—the lower sandstone series—consist predominantly of dark fine-grained quartzite or highly indurated sandstone. Thin argillitic or phyllitic partings are common. Cross-bedding and extensive ripple-marked surfaces, as is well shown in Black Canyon, are characteristic features. In places, as in Black and Silver canyons, a pronounced slatiness has been imposed on the rocks, commonly at a considerable angle to the stratification.

The rocks above the lower quartzitic sandstone series consist of an alternation of limestones and shales, aggregating 2,600 feet in thickness. Certain of the limestone beds are crowded with the remains of Lower Cambrian corals (Archæocyathinæ).[1]

The upper sandstone series resembles the lower sandstone series; it is best shown on the summit of the range south of the Saline Valley road. It is overlain by black slates, which weather with a pronounced red tint, and by arenaceous limestones containing trilobite fragments.

ORDOVICIAN SYSTEM.

The Ordovician rocks overlie the Cambrian conformably and consist of a basal series of heavy-bedded limestones, aggregating 3,600 feet in thickness, succeeded by 800 feet of quartzite, shale, and limestone. They are best exposed along Mazourka Canyon, on the west flank of the Inyo Mountains, where their stratigraphic relations are partly determinable; thence they extend across the mountains, but along the east flank of the range south of Waucoba Mountain they are so folded, overturned, faulted, and brecciated and are so intruded by igneous rocks that their stratigraphy is probably impossible of determination.

In the upper portion of the Ordovician were found Hormotoma, Fusispira, Diplograptus, and Amphion. In addition to these there were a number of other gastropods, ostracodes, and brachiopods not yet identified by Mr. Kirk.

[1] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 49, 1895, p. 141.

DEVONIAN SYSTEM.

Above the Ordovician rocks are 1,400 feet of impure limestones, cherty in places, which are assigned to the Devonian. They are conglomeratic at the base of the section but rest in angular accordance on the subjacent Ordovician rocks. They are best exposed in the foothills east of Citrus.

The fossils found in these rocks include Striatopora, Cladopora, Ptychophyllum, and Chonetes. Concerning these Mr. Kirk reports: "This is an assemblage of fossils which strongly suggests Silurian but which I think may be more safely called Devonian. Fossils specifically identical with these have been found in the White Pine district of Nevada and have always been listed as Devonian by Walcott and others."

CARBONIFEROUS SYSTEM.

The Carboniferous is extensively developed in the southern part of the Inyo Mountains, attaining a thickness very roughly estimated at 5,000 feet. Portions of the section were measured carefully at several points in units aggregating 3,000 feet, but at no place was a complete section found.

The rocks comprise limestone, shale, and some quartzite, the limestone predominating. A conglomerate marks the base of the Carboniferous, indicating an unconformity between it and the underlying Devonian, but the strata rest in angular accordance on the subjacent rocks.

The lower portion of the Carboniferous section consists largely of heavy-bedded limestones; the upper portion consists of thinner-bedded limestones, ranging on the average from 6 inches to 2 feet. The upper 2,000 feet of the Carboniferous rocks, as exposed southwest of Cerro Gordo, weather in brilliant tints and resemble closely the overlying Triassic rocks, from which, however, they are readily distinguished by the presence of Fusulina.

The top of the Carboniferous section is characterized by the presence of a massive conglomerate composed largely of chert fragments, but at many places this conglomerate is faulted out, so that the contact of the Carboniferous and the Triassic is commonly a fault contact.

Locally the Carboniferous is fossiliferous, containing the following forms, among others: Fusulina, Productus, Derbya, Amplexus, and Goniatites.

TRIASSIC SYSTEM.

The Triassic rocks consist predominantly of thin-bedded limestones and calcareous slates, together with some hard, massive black shales occurring mainly north of Union Wash. The rocks weather as a rule in rather brilliant tints, buff and terra cotta prevailing.

The strata are faulted and closely folded and are overturned at many places; they were evidently far more susceptible to dynamic deformation than the older and more massive formations. Owing to this complex folding the thickness of the Triassic rocks could not be determined accurately, but 5,000 feet seems not an overestimate. The rocks form a belt extending southward from the Reward mine along the west flank of the Inyo Mountains.

Collections of fossils made by J. P. Smith show that this belt includes rocks of Lower Triassic and Middle Triassic age.[1]

QUATERNARY SYSTEM.

LAKE BEDS.

Along the foothills of the White Mountains east of Alvord there is exposed, especially as viewed from Owens Valley, an assemblage of beds strikingly different in aspect from the surrounding bedrock formations. The strata are brilliant white or light gray and are dissected by numerous gulches and sharp ravines, so that a sort of badland type of topography is produced.

The beds of this formation consist of shales, sandstones, conglomerates, thin limestones, and arkose grits. All of these, except the limestones and grits, are soft and loosely coherent. They are evenly and persistently stratified and dip westward at gentle angles. Locally the beds, including even the conglomeratic members, are crowded with fresh-water fossils. They were therefore laid down in a lake, and for this lake Walcott,[2] who first described the beds, has proposed the name Waucobi.

Beds possibly of lacustral origin occur east of Citrus and also southeast of Keeler. Along the Keeler-Darwin road, in the broad basin between the Inyo and Coso mountains, is an extensive exposure of what is very probably a series of lake beds. They consist of loose granitic detritus, as a rule rather coarse. Stratification is not well developed, though some beds of arkose grit, 1 to 2 inches thick, are firmly enough cemented to form distinct strata. Pumiceous rhyolite tuffs become prominent toward the top of the section, especially along the flanks of the Coso Mountains. The volcanic members are well shown east of the divide between Owens Lake and the drainage to the south. A breccia of rhyolite pumice forms beds ranging from a few inches to 30 feet in thickness. In the thicker beds the pumice

[1] Smith, J. P., Comparative stratigraphy of the marine Trias of western America: Proc. California Acad. Sci., 3d ser., vol. 1, 1904, pp. 350–351, 356–357.

[2] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range and the lake beds of Waucobi embayment, Inyo County, Cal.: Jour. Geology, vol. 5, 1897, p. 340.

fragments attain a length of 6 inches. Slabs of coarsely crystalline gypsum an inch or so thick were noted but are not well enough exposed to show whether they are contemporaneous chemical precipitates. These rocks strike north and south and dip 10°–14° W.

Fossils found by Walcott in the lake beds east of Alvord were identified by W. H. Dall, who reported: "Any of them might be recent or Pliocene; my impression from the mass is that they are Pleistocene."[1] As the lake beds are unconformably overlain by indurated conglomerate, locally containing slabs of the underlying lake-bed grit, and as this conglomerate itself has been considerably dissected, it seems probable, from the length of the erosional history thus involved, that the lake beds are of early Pleistocene age or even of Pliocene age.[2]

ALLUVIAL DEPOSITS.

Deposits of gravels and sands occur throughout the White and Inyo mountains and on both flanks of the range. The most notable accumulation of this kind is afforded by the series of ancient alluvial cones best developed at Black and the adjoining canyons along the front of the White Mountains. The alluvial deposits here form the foothill portion of the range, extending up to an elevation of 6,600 feet, or 2,600 feet above the floor of Owens Valley.

As observed from a distance of a mile the alluvial deposits appear to be fairly well stratified, a feature that has led some observers to call them " lake beds," but actual examination at the outcrops shows that the seemingly even stratification is at best a rough, uneven, discontinuous layering.

By far the best developed of the old alluvial cones is that in Redding Canyon; it is, moreover, deeply dissected and the canyon affords a number of fine vertical sections that show the constitution and structure of the deposit. It consists of angular gravels, unshingled, unsorted, and rudely layered. A noteworthy characteristic is the large number of granite bowlders, 6 feet in diameter being a common size, though some attain a size of 12 feet. The deposit is semi-indurated, so that great masses spall off. A striking feature, also determined by the partial cementation of the gravels, is produced by the earth pillars or " toad stools " capped by granite bowlders. Near the mouth of the canyon, at an altitude of 4,500 feet, there occurs an intercalated bed of white rhyolite pumice breccia 2½ feet thick, which is rather well stratified. In appearance and composition this bed coincides with those found at the top of the lake-bed series along

[1] Walcott, C. D., op. cit., p. 342.

[2] See also Trowbridge, A. C., The terrestrial deposits of Owens Valley, California: Jour. Geology, vol. 19, 1911, p. 725.

the western flank of the Coso Mountains, and this lithologic resemblance suggests synchronous deposition. The pumice bed and the associated alluvial beds dip 7° W., but a short distance farther west the dip steepens to 16°, and this abrupt steepening indicates that the beds have been deformed since they were laid down.

Pumiceous rhyolite occurs in the sand beds or loose sandstones at McMurray Springs and forms a conspicuous white stratum in the alluvial gravels at Devils Gate, on the Saline Valley road. Along this road the old alluvial gravels extend continuously to the summit of the range at an altitude of 7,500 feet, and even across the divide down at least to 7,300 feet. Here, as noted along the June Smith cut-off, the gravels are cemented by a white matrix composed largely of particles of pumiceous rhyolite. Rhyolite tuff is also embedded in the coarse gravels, capped by basalt sheets, occurring on the east flank of the Inyo Mountains northwest of Willow Creek.

The gravels east of Alvord rest unconformably on the lake beds of the Waucobi embayment. Owing to the fact that the lake beds are poorly lithified few characteristic rock fragments derived from them occur in the overlying deposits, so that it is in many places difficult to determine that an unconformity actually exists. Furthermore, the lake beds, because of their loose and incoherent character were easily reworked, and the material thus derived was incorporated in the overlying deposits without essential change of appearance and now forms the matrix of the gravels. In this way deposits simulating littoral phases of the lake beds were formed, so that the discrimination of true lake beds from terrestrial deposits is no easy matter.

Well-rounded gravels, with which rhyolite tuff is commonly associated, occur generally below the basalt sheets that form cappings on the high summits in the eastern part of the White Mountains and in the Inyo Mountains southeast of Keeler. They occur at elevations as high as 8,300 feet. In places they cap the divides between such deep intermontane depressions as Deep Spring and Eureka Valley. From the fact that these gravels are thoroughly water worn and are locally auriferous it seems probable that they represent old river channels and may be older than the material of the alluvial-cone type.

The present series of alluvial cones that form so prominent a feature along the east wall of Owens Valley were derived largely from the erosion of the older alluvial cones. They head in the deep canyons penetrating the west flank of the range and attain elevations ranging from 2,000 to 2,500 feet above the floor of the valley.

IGNEOUS ROCKS.

ANDESITES.

Andesitic rocks form a belt extending along the west flank of the Inyo Mountains from Union Wash to a point near the south end of the range. They are of volcanic origin and comprise a stratified series of lavas, breccias, and tuffs. Thick sheets of lava predominate at most places, so that as a rule it is difficult to ascertain the internal structure of the volcanic series.

East of Swansea the volcanic belt is approximately 10,000 feet wide. The general attitude of the beds is steep, the dip on the east side of the belt, where it is clearly determinable, being 70° W. If the belt represents a closely appressed syncline, as is indicated by the general structure of the range, then the probable thickness of the andesitic series is 4,500 feet. (See fig. 6.) This estimate doubtless gives a minimum thickness, for both contacts along the line of the measured section are fault contacts, although the amount of faulting that has taken place along them seems small.

The andesites are highly porphyritic, carrying numerous large phenocrysts of plagioclase feldspar. They are more or less thoroughly altered and are consequently of some dull, subdued color—grayish green, dull reddish, etc. They are well exposed on the Cerro Gordo road, where heavy sheets of conspicuously porphyritic andesite are shown, reddish on weathered surfaces and bluish gray on fresh fractures. A roughly schistose or sheared structure has been impressed on the volcanic rocks, especially on the tuffs and other pyroclastics.

Intrusive rocks have invaded the andesites—granites in the area northwest of the Burgess mine; aplite in dikes and as a large

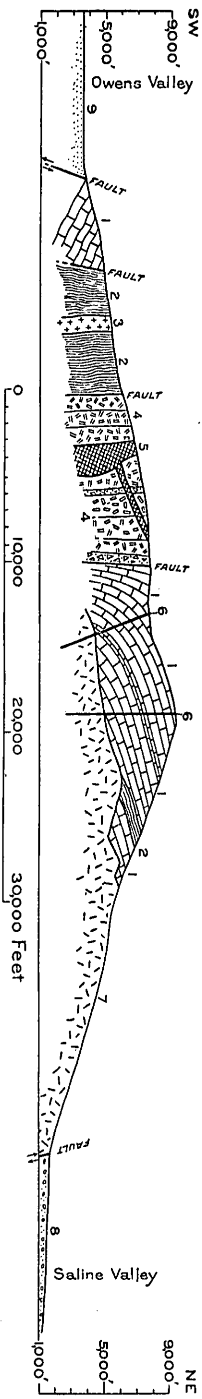


FIGURE 6.—Diagrammatic section across Inyo Mountains at Swansea, Cal. 1, Carboniferous limestone; 2, Carboniferous shales; 3, felsite; 4, Triassic andesite lavas, breccias, and tuffs; 5, aplite; 6, diorite porphyry; 7, quartz monzonite, diorite, and hornblendite; 8, alluvium; 9, lake beds.

mass east of Swansea, as shown in figure 6; and diorite porphyry in dikes intersecting them at several localities.

The age of the andesitic series is probably late Triassic. The evidence on which this determination is based was found in the ridge on the south side of Union Wash, where the basal portion of the volcanic series, consisting of andesitic breccias, interleaves with the underlying limestones of Middle Triassic age. Angular fragments of these limestones are common inclusions in the breccias. It is therefore certain that the andesitic series is younger than the Middle Triassic limestones, and the most probable interpretation of the facts at hand is that Middle Triassic sedimentation in this locality was terminated by a great outburst of volcanic activity.

GRANITIC ROCKS.

Granitic rocks occur in large volume in the White and Inyo mountains. Extensive areas are exposed on the east side of the White Mountains, but on the west flank only small masses occur, as that in Redding Canyon and those east of Alvord. About half of the Inyo Mountains shows granite at the surface, and it occurs in great amount on both sides of the range. Many unmistakable features indicate, moreover, that granite underlies the remainder of the range at no great depth. These features are the occurrence of aplite intrusions at considerable distances from surface exposures of granite; the prevalence of diorite porphyry dikes, many of which closely approach diorites in granularity; and the occurrence of masses of garnet rocks, which are ascribable to the metamorphic effects produced by underlying granitic intrusions.

The average granitic rock is a quartz monzonite composed of plagioclase, orthoclase, quartz, hornblende, and biotite. From this average the granitic rocks range on the one hand to varieties that may appropriately be termed granite, such as the mass east of Citrus, and on the other hand to quartz diorite, diorite, and hornblendite. The dark heavy hornblende-rich varieties are especially prevalent in Daisy Canyon, on the east flank of the Inyo Mountains, and along the crest of the range northward from New York Butte.

The intrusive character of the granites is made apparent most plainly by the extensive contact metamorphism that they have induced in the inclosing sedimentary rocks. This effect is displayed most notably, perhaps, in the great belt of chiastolite hornfels formed as a result of the recrystallization of a belt of shale occurring in the lower part of the Carboniferous section of Mazourka Canyon. The belt of chiastolite-bearing rock has a length of over 10 miles, extending from the foothills southeast of Citrus to and beyond Santa Rita Flat, and attains a width of over 1 mile at Barrel Springs.

The chiastolite, which is recognizable by its characteristic carbonaceous crosses, is present across the entire width of the belt, but toward the granitic contact the matrix in which the chiastolite prisms are embedded becomes more crystalline, and locally tourmaline becomes associated with the chiastolite as another visible constituent of the hornfels.

The age of the granitic intrusions, so far as it is determinable in the White Mountains, is post-Cambrian and pre-Pliocene. In the Inyo Mountains the age is determinable as post-Triassic and presumably pre-Pliocene. It is believed that all the intrusive masses are essentially of the same age, although this surmise is not susceptible of proof, and that they were probably intruded contemporaneously with those of the Sierra Nevada, which forms the opposite wall of Owens Valley. That successive intrusions did in fact take place within the Inyo Mountains was definitely determined at one locality at least. Southeast of Mount Whitney station a white granite, which is devoid of ferromagnesian minerals except rare flakes of biotite and is characterized by an abundance of subhedral quartz crystals, forms a prominent knob projecting out into Owens Valley as a spur from the main range, and a gray biotite-quartz monzonite forms the foothills of the main range. The two granitoids contrast strikingly, and the white granite proves to be the younger intrusive mass. The white granite carries considerable plagioclase and is therefore in all probability a salic differentiate of the quartz monzonite magma, genetically coordinate with aplite and intruded shortly after the main intrusion.

APLITE.

Dikes of fine-grained equigranular white rock termed aplite occur around the peripheries of the granitic intrusions, both in the granite itself and in the surrounding rock. They are composed almost wholly of feldspar and quartz. They were noted as particularly abundant in the zone of garnetization of the limestones adjacent to the granite mass north of Antelope Spring; these aplites show in places a small amount of purple fluorite. East of Swansea, as already mentioned, aplite intrudes andesitic rocks.

PORPHYRY INTRUSIONS.

Dikes and irregular masses of porphyry occur throughout the Inyo Mountains, cutting all the different formations of pre-Pliocene age, both igneous and sedimentary. They are particularly numerous in the vicinity of the large granitic masses and are there of obviously more crystalline texture. In the field most of the dikes would be designated diorite porphyry, because they show porphyritic plagioclase crystals embedded in a microcrystalline groundmass, but microscopic examination reveals the fact that some, such as that occurring northwest of Cerro Gordo, should be called monzonite porphyry. The distinction, however, is of no great importance. The dikes traversing the sedimentary rocks exhibit strongly chilled margins, which thereby take on an andesitic appearance.

The greater prevalence of the dikes and their more highly developed crystallinity in the neighborhood of the great granitic masses shows that they belong to the closing manifestations of the intrusive activity of the quartz monzonite magma.

FELSITE.

Felsite dikes were noted only in the southern part of the Inyo Mountains, more particularly in the lower slopes of the range east of Swansea and Keeler. They are dense-grained rocks containing minute inconspicuous phenocrysts of feldspar and resemble dense quartzite—a resemblance that is not diminished by the fact that they are generally intruded parallel to the stratification of the inclosing rocks. Under the microscope they show small sporadic orthoclase phenocrysts embedded in an extremely fine grained groundmass of quartz and orthoclase; ferromagnesian minerals are totally absent.

Some of the larger intrusions of felsite were slightly impregnated with pyrite, and the oxidation of this mineral has caused the outcrops to take on a rusty orange-colored tint.

RHYOLITE.

Breccia and tuff composed of pumiceous white rhyolite occur at many places throughout the region, as described in part in the section on the older alluvial deposits. The greatest thickness noted is 200 feet, as shown on the Saline Valley road 3 miles north of Rattlesnake Cabin, where the rhyolite tuffs are overlain by heavy flows of basalt.

The rhyolite is composed of a highly vesicular glass, silky in appearance on fresh fracture, holding phenocrysts of quartz, sanidine, and biotite. The quartz predominates, sanidine and probably other feldspars are common, but biotite is rare and is generally absent.

BASALT.

Basalts were erupted during two separate periods—the earlier in early Pleistocene time and the later in geologically very recent time.

The earlier basalts form a prominent part of the range southeast of Keeler, and the whole south end is buried under lavas. At an altitude of 6,300 feet the floor on which they were erupted—a nearly horizontal surface—is well shown. Beneath the basalt sheets as exposed here is a 10-foot stratum of tuff composed of pumice fragments of oxidized, highly vesicular basalt; the tuff itself rests on gravel deposited unconformably on the eroded edges of the Triassic. The horizontal lava sheets are step-faulted, as is graphically shown in the deep canyons eroded back into the basalt plateau, and it seems probable that the simulated appearance of a great lava flow descending from the plateau down to the level of the broad pass between the Inyo and Coso mountains is due to a great number of such step-faults.

Basalt sheets overlie the lake beds in places in the intermountain area between the Inyo and Coso mountains; they overlie ancient alluvial cones on the east side of the Inyo Range, and form a conspicuous series of plateaus sloping southeastward on the east side of the White Mountains at altitudes ranging from 5,500 to 10,500 feet. The thickness of these basalt cappings is about 125 feet.

The basalts are highly olivinitic varieties. A specimen from the head of South Fork of Crooked Creek is characterized by abundant phenocrysts of olivine and of augite in irregular stellate groups; feldspars do not occur among the porphyritic constituents but only in the groundmass, which is composed of augite, labradorite, and magnetite.

A large basalt flow of very recent origin was extruded at the base of the mountains northeast of Aberdeen, in Owens Valley. It flowed out over Recent alluvium and is exceedingly vesicular and scoriaceous. The basalt is an olivine-bearing variety, rather feldspathic, so that the holocrystalline form is dark gray. It is essentially similar in appearance to the earlier basalts. Ejection of cinders closed the eruption. This basaltic outburst was in all probability contemporaneous with the outpouring of lavas and the formation of cinder cones on the opposite side of Owens Valley, along the flank of the Sierra Nevada.

MINERAL RESOURCES.

PRINCIPAL ORES.

The metalliferous mineral resources of the Inyo and White mountains in the order of their present importance are zinc carbonate, argentiferous galena, gold-quartz, and copper ores. Formerly argentiferous galena ore was the principal resource, the famous mines at Cerro Gordo alone having yielded $7,000,000 in silver and lead.

HISTORICAL NOTE.

Mining began in 1861, when the Russ mining district was established in that portion of the range east of Independence. From 1869 to 1877 the region enjoyed a period of great activity, for it was then that Cerro Gordo was yielding its great output of base bullion. The completion of the Colorado & Carson Railroad to Keeler in the early eighties served to stimulate the mining industry to some extent, although not as much as was expected, and the region never regained the prominence it held during the flush days of Cerro Gordo. About 1907 a revival of interest in the mineral deposits of the Inyo Mountains took place, the most notable result of which has been the development of zinc ore on a commercial basis. Mining and prospecting were not active in the White Mountain Range during 1912 except at Cerro Gordo, which yielded practically the entire output of metal of the region—zinc, lead, and silver.

OCCURRENCE.

The ore deposits occur most abundantly in the southern part of the range—that is, in the Inyo Mountains—and the preponderant part of the metallic output has come from that part of the range. This distribution of the mineral resources coincides with the distribution of intrusive granite, which, as already pointed out, is far more abundant in the southern part of the range than in the northern, or White Mountain, part. The zinc, lead, silver, and copper deposits occur as a rule in limestone; the gold deposits seem closely linked to the presence of granite, occurring chiefly in the marginal zone of the granite masses or in the country rock immediately adjacent to them. Ore deposits have not been found in the central portions of the larger granitic areas.

ZINC ORES.

OCCURRENCE AND ORIGIN.

Zinc ore composed essentially of the carbonate smithsonite occurs at Cerro Gordo; in fact it was the discovery of this ore, whose presence was previously unsuspected, that led to the recent revival of mining at that camp. It has been found nowhere else in the Inyo Mountains. The zinc ore forms pipes and irregular masses lying principally in the limestone footwall of the old galena stopes; it occurs immediately below the lead-ore bodies formerly worked and extends as far as 100 feet laterally from them.

The origin of the zinc ore is essentially as follows: The primary ore in the deposits formerly worked for lead and silver consisted of galena containing a small amount of admixed sphalerite; oxidation converted the sphalerite to the soluble zinc compound, zinc sulphate, which was then carried by downward-moving water into the footwall of the lead-ore body; here a reaction took place between the zinc-bearing solution and the limestone, and the zinc was precipitated as the carbonate smithsonite.

CERRO GORDO MINE.

LOCATION.

The property now known as the Cerro Gordo mine is a consolidation of the Union and Santa Maria mines, the two mines that furnished the bulk of the output of argentiferous lead ore to which Cerro Gordo owes its fame. Cerro Gordo has been the only notable producer of silver-lead ore in the State of California; its present importance, however, is due mainly to the discovery of bodies of zinc carbonate ore, which occur as footwall appendages to the lead chambers formerly worked.

The mine is situated near the summit of the Inyo Mountains, east of Owens Lake. At the Belshaw or principal shaft the altitude is 8,500 feet—nearly 5,000 feet above the town of Keeler, the terminus of the Nevada & California Railroad. In an air line the mine is 5½ miles northeast of Keeler; by wagon road it is 8 miles, and the grade from the valley is steep. The mine lies immediately below the bold scarp on the west flank of Cerro Gordo Peak, which rises to an elevation of 9,217 feet and is a prominent landmark as seen from Owens Valley.

HISTORY.

Cerro Gordo, according to Loew,[1] who visited the mines in 1875, was discovered in 1866 by Mexicans—Pablo Flores and his companions. By others the date of discovery is given as 1861. Be that as it may, the deposits were worked by the Mexicans on a small scale only, the ores being smelted in vasos, and the district did not become notably productive until its mines were taken over by Americans in 1869. The Union mine came into the possession of M. W. Belshaw and V. Beaudry; the Santa Maria and allied properties were shortly afterward acquired by the Owens Lake Silver Mining & Smelting Co., of New York. The ores were smelted at three reduction works. Those from the Union mine were treated at Belshaw & Judson's furnaces, situated above the portal of the Omega tunnel, and at Beaudry's furnace, just west of Cerro Gordo camp; those from the Santa Maria mine were smelted at the Owens Lake Silver Mining & Smelting Co.'s furnaces at Swansea, near the shore of Owens Lake.

Scarcity of water, scarcity of fuel, and high transportation charges made mining and reduction costs large; nevertheless the period from 1869 to 1876 was one of great activity. Water was piped to Cerro Gordo from a distance of 11 miles, the lift being 1,875 feet; charcoal burned from piñon and mountain mahogany, which grow in scattered stands in the higher portions of the Inyo Range, cost at the furnaces at Cerro Gordo 32½ cents a bushel; all freight

[1] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., 1876, p. 62.

had to be hauled across the desert from Los Angeles, a distance of 275 miles, at a cost of 3 to 6 cents a pound.

In 1871 the production of the district was $300,000, the recovery being only 50 to 55 per cent of the lead. In 1872 3,220 tons of base bullion carrying 140 to 150 ounces of silver a ton was produced, which, with silver at $1.2929 an ounce and lead at 6 cents a pound, aggregated $977,255 in value, or approximately $303 a ton.[1] Eilers, who visited Cerro Gordo in 1872 and described the metallurgical processes in use there, estimated that the ore of the Union mine, though the average content was not precisely ascertained at the works, contained about 34 per cent of lead, the slag carrying 15 per cent of lead.[2] Quartzose silver ores, obtained from the Ignacio, Belmont, and other mines in the vicinage of Cerro Gordo, were added in small quantity to the furnace charge for the purpose of concentrating their silver in the lead. Economy of fuel was obtained by means of "an almost unprecedented loss of lead." Eilers concluded that "the whole management of the works is rather calculated to create the suspicion that the proper composition of the charge is not understood. It is certain that either by an addition of iron oxide to the present charge, or by omitting the addition of the quartzose silver ores altogether, far better results might be obtained than at present."[3]

These suggestions seem to have borne some fruit, for the old slag dumps, as sampled by the present management of Cerro Gordo, show a content of not over $5 a ton in silver and lead; only by sorting out material containing unfused lumps of ore it is possible to obtain a product averaging $15 a ton.

It is recounted that at one time in 1873 $2,000,000 worth of bullion was corded up on the shores of Owens Lake awaiting transportation out of the valley, and bars of base bullion were even used to construct cabins as temporary shelter for the miners.

Litigation commenced at this time. The San Felipe Co., most of whose stock was owned by the Owens Lake Silver Mining & Smelting Co., claimed discovery title to the Union mine, and a verdict was rendered in its favor. The case was then appealed to the United States Supreme Court, where it lay for several years.

The maximum annual output—5,600 tons of base bullion—was made in 1874. From December 1, 1873, to November 1, 1874, the Union mine produced 12,171 tons of ore of an average assay content of 47 per cent of lead and 87 ounces of silver to the ton.

According to M. W. Belshaw,[4] for the period February 1 to October 1, 1876, the total cost per ton for mining and reduction was $19.96.

[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, p. 26.
[2] Idem, p. 356.
[3] Idem, p. 355.
[4] Fourth Ann. Rept. California Min. Bur., 1884, p. 225.

The quantity of ore treated was 9,950 tons; the lead produced was 1,325 tons. The recovery was 64 per cent of the lead assay and 90 per cent of the silver assay. According to these figures the ore as mined carried 21 per cent of lead and was therefore of considerably lower grade than that mined a few years earlier.

It is impossible to give an accurate figure for the total output of Cerro Gordo during its most prosperous years. The figures now current in Owens Valley range around $20,000,000, but these estimates surely show the generous influence of time and tradition. The estimates given in contemporary or nearly contemporary reports range from $6,500,000 to $15,000,000. The total output of base bullion from 1869 to 1876, inclusive, obtained by summing up the yearly production given in Raymond's annual statistics of mines and mining in the States and Territories west of the Rocky Mountains, is approximately 22,500 tons. On the assumption that the average value was $300 a ton—as in 1872—the value of the total output of Cerro Gordo during its most prosperous period was $6,750,000, or, in round numbers, $7,000,000.

The mines, although consolidated after the settlement of the litigation, were shut down about 1877, mainly, it would appear, because the large bonanza bodies of argentiferous galena had been worked out. In the early eighties the Carson & Colorado Railroad, a narrow-gage line which connected with the Central Pacific Railroad at Reno, was completed to Keeler and was expected to revive the mining industry at Cerro Gordo. The mine, however, was worked spasmodically by lessees until it was acquired by the Great Western Ore Purchasing Co., in 1905. A small production was made by this corporation in 1907. Subsequently the property was taken over by the Four Metals Mining Co., which erected a 200-ton smelter just east of Keeler and built an aerial tramway from the mine to the smelter. This company attempted to smelt the old slags from Cerro Gordo and to work the mine, but went into insolvency. The present operators, who had obtained from the Four Metals Mining Co. a lease to extract the zinc ore of the mine, then took over the property by purchase of the bonds of the insolvent corporation. During 1912 litigation was in progress concerning the ownership of the property.

To whom belongs the credit of recognizing the occurrence of zinc ore at Cerro Gordo is not known. Its discovery in important quantities and its exploitation on a commercial base are due to L. D. Gordon, of the Cerro Gordo lease.

DEVELOPMENTS.

The underground workings are said to aggregate 20 miles in length. The Belshaw shaft, from which five levels have been driven, is 900 feet deep, and from the 900-foot level a winze extends down to the 1,150-foot level.

An aerial tram connects the mine with the smelter, which is situated half a mile east of Keeler. The nominal capacity of the tram is 50 tons a day, but this is frequently lowered by breakdowns. The difference in elevation between the terminals is approximately 4,500 feet; nevertheless the tram must be driven by a steam engine. Crude oil is at present employed as fuel in the operation of the hoist and the tram, but if developments warrant it electric power will be obtained from one of the hydroelectric power companies operating in Owens Valley.

Despite the considerable depth of the mine, the water level has not been reached. In the lower levels there was (in September, 1912) a slow trickling or "sweating" from the walls of the drifts.

GENERAL GEOLOGIC FEATURES.

The prevailing rock at the mine is a dense, fine-grained white marble; with this are associated some interstratified slate and a number of dikes of diorite and of monzonite porphyry which lie parallel or approximately parallel to the stratification of the inclosing beds.

The rocks in the immediate vicinity of the mine are part of a formation of Carboniferous age which is extensively developed in the surrounding area. This formation consists principally of limestone, with some interstratified shale or slate and quartzite. A belt of shale, probably 300 feet thick, lies northwest of the mine, and is underlain by fine-grained white quartzite, 100 feet thick. The strike is N. 30° W. and the dip 45° W. The shale is in places highly fossiliferous, carrying Derbya, Goniatites, pelecypods, and other forms, which fix its age as Carboniferous.

The intercalated beds of shale and quartzite prove useful horizon markers and show that faulting of a complicated character has taken place, centering particularly at the Cerro Gordo mine. If the attempt is made to trace the 100-foot quartzite member from the northwest toward the mine, it is found that near the mine the quartzite is cut out by a fault, trending northeastward. The displacement of the fault is of large and unknown magnitude, and the details are obscured by talus covering the rocks. The fault zone appears to be made up of a number of diversely oriented blocks. For example, some 600 feet north of the shaft house there is an outcrop of blue crinoidal limestones interbedded with quartzitic strata, striking east and west and dipping 50° S.; 50 feet southwest of this exposure the rocks strike N. 15° W. and dip vertically, and other similarly discrepant measurements can be obtained—facts indicating that the fault zone is probably made up of a mosaic of small blocks.

East of the mine the limestones as a rule dip eastward, the dip averaging 45° E. on Cerro Gordo Peak and flattening farther east, being practically horizontal near the Newtown mine. At this locality a remarkably fine example of a bedding fault breccia is shown. The breccia, lying between two beds of limestone, consists of long slabs of dark-gray limestone and a light-buff variety held in a matrix of very coarse white calc spar, individuals of which show cleavage surfaces 6 to 8 inches broad. The breccia is locally 4 feet thick. On the face of the cliff southwest of the Newtown shaft house a reverse fault of 10 feet displacement is well shown. The value of quartzite beds as indicators of faulting is illustrated effectively on the slopes behind the Newtown mine. Here within a length of a few hundred feet the rocks are intersected by four faults, marked by fault breccias, with displacements, as measured on the interstratified beds of quartzite, that range from a few feet to 75 feet. One of these fault breccias carries numerous fragments of gossany iron oxide.

The examination of the geologic structure around Cerro Gordo therefore shows that the rocks have been subjected to severe faulting. Some of this faulting took place prior to the formation of the ore bodies and some after the ore bodies had been formed, but the post-mineral faults are probably of much smaller magnitude than those of premineral origin. Underground examination in the Cerro Gordo mine is confirmatory of the facts shown by the study of the surface geology, for many faults are exposed in the workings. The correct elucidation of the faulting may prove to be a matter of highest practical importance, for a possibility exists that valuable ore bodies may have been cut off by faults and that the faulted segments were not found by the former operators. In working out the character and amount of displacement along the faults, the diorite porphyry and other dikes should prove of great help.

Northwest of Cerro Gordo monzonite porphyry forms a small mass intrusive into the surrounding shale. The porphyry is characterized by an abundance of feldspar phenocrysts and hornblende prisms, the phenocrysts being in certain parts of the mass so closely crowded as to give the rock a granitic appearance. The specimen examined microscopically was found to show essentially these features: Plagioclase ($Ab_{62}An_{38}$) forms the predominant phenocryst and is associated with phenocrysts of orthoclase and hornblende; the porphyritic constituents are inclosed in a groundmass composed of orthoclase and quartz and forming but a small proportion of the whole rock. Titanite, which is rather abundant, apatite, and magnetite are the accessory minerals.

This intrusive mass of monzonite porphyry is in all probability an unroofed upward extension of the granitic mass that underlies the whole Inyo Range at no great depth. Although along the crest granite is not encountered for a distance of 10 miles north of Cerro Gordo, yet toward the east, where the range drops off abruptly toward Saline Valley, 7,000 feet below, great quantities of granitic rock are exposed. Furthermore, masses of garnetized limestone occur at several mines and prospects west and southwest of Cerro Gordo, as at the Ignacio, Ventura, and others—a fact which indicates that the rocks at Cerro Gordo at the time of the intrusion of a granitic mass, now unexposed, were situated near the outermost limit of the zone of metamorphism produced by the invasion.

In the mine occur dikes which appear to have been originally similar to the monzonite porphyry northwest of Cerro Gordo. They have, however, been altered by three distinct kinds of metamorphism, successively applied—(1) alteration by shearing, (2) alteration accompanying the primary mineralization, and (3) alteration by oxidation and by the downward percolation of sulphate solutions. Any one of the alterations produced by these processes might be sufficient to obliterate the original features of the dikes; it follows, therefore,

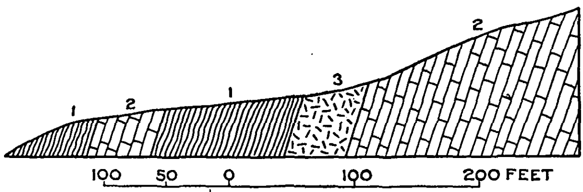


FIGURE 7.—Diagrammatic section along the line of the Union tunnel, Cerro Gordo, Cal. 1, Slate; 2, marble; 3, monzonite porphyry.

that the precise identification of some of these rocks is impossible; in fact, certain narrow dikes, which are considerably sheared, are difficult to distinguish from slate.

One of the most prominent dikes in the mine is that cut in the Union tunnel, in the footwall crosscut of the Santa Maria pit, where it is 50 feet wide, and in the Zero level. The dike apparently conforms in the main with the strike and dip of the bedding of the inclosing rocks. (See fig. 7.) In the Union tunnel, however, the contacts are much shattered. The west contact strikes N. 15° W. and the east contact N. 35° W., both being nearly vertical. The dike is overlain by a shale belt 105 feet wide and is underlain by massive white marble. In the Zero level, which is several hundred feet south of the Union tunnel, the dike lies within the shale belt and therefore probably cuts across the trend of the formation at a narrow angle. The dike is of conspicuously porphyritic appearance, owing to the prevalence of large tabular feldspar crystals; it is considerably sheared and is deeply stained by oxides of iron and manganese. Specimens from this dike are unsuitable for precise determination; some material from the 400-foot level, taken near the intersection by the San Felipe quartz vein, was found to be a porphyry much altered by carbonatization.

Other dikes differing considerably from the monzonite porphyry were noted in the underground workings. They range in different dikes from 4 to 25 feet in thickness; on the 900-foot level one of these dikes was found to be intrusive into the monzonite porphyry. They are gray, fine-grained granular diorites carrying numerous small black prisms of hornblende; a characteristic feature is the presence of corroded phenocrysts of quartz, although these are rare and widely scattered. One of the best-preserved dikes is that shown on the 400-foot level, 200 feet north of the shaft. Under the microscope, however, even this proved to be highly altered and to consist of epidote, chlorite, feldspar, and sericite.

LEAD ORE BODIES.

The lead ore bodies of Cerro Gordo consist of lenticular masses distributed through a zone 2,000 feet long and several hundred feet wide. The predominant rock of the ore-bearing zone is a white, finely saccharoidal marble, essentially a pure calcite rock, which on freshly fractured surfaces shows a slight bluish tint. Slate and igneous rock—the dikes of diorite and porphyry—as already described, occur also within the ore-bearing zone, but the ore bodies are inclosed principally in the marble. Certain important ore bodies, however, rested on a footwall of slate, as, for example, that taken out from the Santa Maria pit.

The rocks of the ore-bearing zone strike in a north to northwesterly direction and dip on the average 70° SW.; the ore bodies conform to the trend of the inclosing rocks. To cite an example, the Jefferson stope—the stope farthest southeast—strikes N. 35° W. and dips 75° SW.

The lead ore bodies formerly worked attained thicknesses of 40 feet. The Jefferson stope is from 3 to 20 feet wide and averaged 70 feet in length; the Union stope, from which $3,000,000 worth of silver and lead is supposed to have been extracted, extended down to the 550-foot level. According to Raymond [1]—

> The Union, the highest on the mountain side, has undergone considerable development during the past year. On the surface the ore body strikes about S. 30° E. and dips steeply to the southwest, but at the level of the main working tunnel, which strikes the Union at a depth of about 175 feet from the surface, the ore body begins to stand nearly perpendicularly and continues so for a depth below this level of 165 feet, the lowest point reached in September, 1872. At a depth of 200 feet below the tunnel a branch leaves the main ore body toward the west. Its dip is very flat, and it has been followed over 100 feet, always in very excellent ore, the greater part of which is galena. This

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, pp. 18–19.

branch is about 3 feet thick. It is thought and hoped by the owners of the Union that it will eventually run into the Santa Maria, and as the Union has the older title the independent existence of the Santa Maria would in that case be endangered. The longest level on the vein in the whole mine is the one driven at a depth of 200 feet below the tunnel, and even this one is little over 100 feet long. But the ore deposit, as developed by this level and the work done in the 65 feet below, is of extraordinary extent, being in many places 40 feet wide and nowhere less than 15. At the same time the ore is very solid, being either reddish-yellow carbonate or pure gray carbonate, lying in great blodges in the former. The masses of the latter kind have frequently a diameter of from 3 to 6 feet and always show a concentric arrangement—that is, every mass of this kind which has been cut through by the excavations shows concentric rings around an interior nucleus (generally a small lump of unaltered galena), the rings being somewhat darker than the main mass. This arrangement presents a beautiful aspect and, though common with gray carbonate of lead when lying in a ferruginous gangue, it is not often seen on as large a scale as exposed in the Union. The carbonate ores of the Union, on account of their friability termed "fuse ores" by the miners, average, as delivered to the furnace, about 25 ounces of silver per ton, and the galena from 50 to 80 ounces.

During 1912 lead ore was being mined on the 700-foot level, where it formed a shoot as much as 5 feet wide. It consisted largely of galena, though considerably oxidized, so that cerusite was common, forming a yellowish ocher mixed with anglesite. A small quantity of chrysocolla occurred here also; in fact, chrysocolla is persistent throughout the mine, though nowhere abundant. Linarite, the deep azure-blue double sulphate of lead and copper, and brochantite, a basic sulphate of copper, are found here occasionally. The massive galena contains a small amount of dark-brown or black sphalerite—a fact of great importance in connection with the origin of the zinc carbonate ore.

A shoot of lead ore recently uncovered at the surface, averaging 1 foot or so in width, consists predominantly of galena but contains also some tetrahedrite, sphalerite, and pyrite. The galena has a distinct sheared structure, which is circumfluent around the sphalerite and tetrahedrite. This structure was evidently produced by the crushing of galena into small flat lenticles lying in parallel orientation. Oxidation products, among which bindheimite was the most notable, occur to a small extent associated with the primary lead ore, though not so abundantly as on the 700-foot level. Completeness of oxidation at Cerro Gordo was obviously not determined wholly by depth but was dependent largely on the perviousness of individual ore shoots to oxidizing solutions. Adjoining the lead ore is several feet of zinc carbonate that has replaced the marble wall rock.

The predominant primary mineral in the ore bodies of Cerro Gordo is galena; as minor constituents occur sphalerite, tetrahedrite, and pyrite. By oxidation a multitude of secondary minerals have formed—cerusite, anglesite, bindheimite, smithsonite, calamine, hydrozincite, aurichalcite, chrysocolla, linarite, brochantite, caledonite, limonite, and others. Cerusite and smithsonite are of economic importance; the others are of mineralogic interest only. Linarite deserves mention because of its striking beauty, and Cerro Gordo is in fact a locality well known for this rare mineral; aurichalcite, another comparatively rare mineral, is also noteworthy because it occurs locally in some abundance as small veinlets traversing zinciferous limonite; it is of delicate blue and bluish-green color, though fading on continued exposure to light, and characteristically forms rosettes and fanlike groups of pearly luster.

SAN FELIPE VEIN.

The San Felipe vein cuts diagonally across the silver-lead ore-bearing zone, trending N. 45° W. and dipping 70°–80° SW. It traverses both marble and porphyry and ranges from a fraction of an inch to 18 inches in thickness. The main ore mineral noted is tetrahedrite, with its oxidation products, azurite and malachite, inclosed in a gangue of barite and quartz. The ore is said to carry $100 a ton in silver.

ZINC ORE BODIES.

Occurrence and character.—The zinc ore forms irregular masses and pipes occurring in the limestone walls of the old lead stopes, principally in the footwall. The form of the ore bodies is determined partly by structural features, such as stratification, jointing, and the fracturing that took place after the formation of the lead ore masses. The zinc ore is frozen tightly to the limestone, but there is no gradation between them, although the ore originated clearly by replacement of the limestone.

The first zinc ore taken out was that found in the footwall of the old Union stope; from this 5,000 tons were extracted. On the 400-foot level a pipe 5 feet in dameter and 150 feet long was discovered that averaged more than 40 per cent in metallic zinc. As the zinc mineral in the ore is mainly smithsonite, whose theoretic percentage of zinc is 52, the ore is very pure; considerable quantities have actually contained as much as 50 per cent. The pipe headed toward the Union stope, and with increasing proximity to the old stope there was a notable increase in limonite and kaolin. Near the head of the pipe extensive masses of limonite, including bodies of pure white kaolin as much as 4 feet in thickness, were found. The same phenomenon occurs throughout the mine; the zinc ore becomes, by progressive disappearance of the iron, increasingly purer with increasing distance from the old lead ore bodies. Bodies of zinc ore extend in places at least 100 feet laterally from the lead ore.

The zinc ore consists essentially of the carbonate smithsonite; the impurities with it are limonite and calcite. The ore is of fine-grained texture and dead-white color and hence is known as "dry bone." It is characteristically laminated; the laminæ range from nearly imperceptible thickness to one-half inch and are curiously convoluted, the convolutions being governed by no discernible law. Vugs are common, and are lined with crystalline smithsonite and calamine. Calamine also occurs to some extent in the form of laminæ, and these show a radial fibrous structure. Hydrozincite occurs rarely, chiefly as small botryoidal groups implanted on crystalline smithsonite.

The ore as shipped averages 35 per cent of zinc, the gangue consisting of calcium carbonate and hydrated iron oxide. The ore carries neither silver nor gold. The total production of zinc ore to January 1, 1913, was 10,000 tons.

Origin.—The primary ore bodies as a rule have undergone extensive oxidation. During this process sulphates of lead, zinc, iron, and copper were formed, together with sulphuric acid, which, acting on shale or porphyry, took alumina and silica into solution. The lead sulphate, being insoluble, remained in place and was later transformed into cerusite; the copper also did not travel far, but was precipitated as chrysocolla or as a basic sulphate. Thus in the first stage the zinc and iron were separated from the other metals and, being contained in a solution acting under the influence of gravity, naturally tended to sink into the footwall of the lead ore bodies. Here the solution came into contact with the calcitic wall rock and a further separation took place. The free sulphuric acid present was immediately neutralized and the ferric iron was precipitated as hydroxide according to the equation—

$$Fe_2(SO_4)_3+3CaCO_3+3H_2O=2Fe(OH)_3+3CaSO_4+3CO_2.$$

This reaction has been studied by Meigen, who finds that ferric iron is, even at 15° C., rapidly and completely precipitated as hydroxide from its solutions by calcite.[1] He finds further that ferrous iron and zinc are precipitated more slowly. According, then, to the extent that the iron contained in the solution was in the ferric state, the zinc, which is later precipitated as carbonate, will be proportionately free from iron.

At Cerro Gordo the zinc ore is as a rule remarkably free from iron, indicating, as one possibility, that the iron in the downward-percolating solutions was mainly in the ferric condition. This would be so, if during oxidation there had been available an excess of

[1] Meigen, W., Beiträge zur Kenntnis des Kohlensauren Kalkes: Ber. Naturforsch. Gesell. Freiburgi. Br., vol. 13, 1903, p. 76.

oxygen—a condition likely to arise, among others, owing to the comparatively small amount of pyrite that underwent oxidation in the primary deposits.

After the precipitation of the ferric iron the ferrous iron and the zinc would be precipitated as carbonates. At Wiesloch, Baden, for example, ferrous carbonate is mingled with zinc carbonate in all proportions up to 50 per cent, although the main ore bodies are relatively pure zinc carbonate.[1] By subsequent oxidation the ferrous carbonate may be converted to limonite, and in this way iron-stained zinc carbonate ores would be produced. The separation of the zinc from ferrous iron would be determined by two factors—the concentration of the solutions in zinc and ferrous iron and the relative precipitability of the carbonates of zinc and ferrous iron. The solubility of zinc carbonates and of ferrous carbonate, measured in gram-equivalents per liter,[2] is respectively 1.7×10^{-4} and 6.2×10^{-5}. From these figures it can be inferred that the iron is more easily precipitable and that this favors the segregation of the zinc from the iron. When, however, the concentration of the zinc becomes high relatively to the iron, both metals must come down together. No experimental data are available concerning the fractional precipitation of a mixture of sulphates of zinc and ferrous iron by means of calcium carbonate, but the geologic evidence seems to show that the fractionation as carried out in nature is very complete, provided, as already pointed out, that the thorough separation of the zinc and iron is not due to the previous complete precipitation of the iron as ferric hydroxide.

One of the most striking features of the ore deposits of Cerro Gordo is the localization of the zinc as carbonate in high-grade bodies in comparison with the small proportion of zinc blende contained in the primary ore. The zinc carbonate, as shown in the preceding paragraphs, was derived from the blende by a process involving oxidation, solution, migration, and precipitation; nevertheless the proportion of blende in the unoxidized lead ore now encountered in the mine is extremely small, ranging perhaps from 1 to 2 per cent. The lead ore bodies formerly worked may have been more highly sphalerite-bearing than any ore now visible, but this seems unlikely because in no account hitherto published concerning Cerro Gordo is the presence of sphalerite recorded. It is believed, therefore, that the primary ore found now is an index of the primary ore occurring formerly in the mine. In the shoot of primary ore recently uncovered at the surface the galena contains only a small quantity of sphalerite; nevertheless the galena is bordered by a layer of smithsonite several feet thick. From a consideration of the foregoing

[1] Schmidt, A., Die Zinkerz-Lagerstätten von Wiesloch, Baden: Verhandl. Naturh.-Med. Ver zu Heidelberg, neue Folge, vol. 2, 1880, p. 399.

[2] Data supplied by R. C. Wells, U. S. Geological Survey.

facts it would appear that the zinc, sparsely distributed throughout the primary lead ore, was effectively segregated and concentrated to a remarkable extent during the formation of the secondary ore.

PRACTICAL DEDUCTIONS.

Some deductions of practical importance follow almost obviously from a recognition of the principles governing the formation and origin of the zinc carbonate ore bodies. Certain of these deductions had been recognized at Cerro Gordo as criteria for the search for undiscovered bodies of ore, although the theoretic foundations on which they were based were not known. These deductions are, stated summarily:

1. The zinc carbonate bodies can occur only in the marble, most likely in the footwall zones of primary lead ore deposits. The largest zinc deposits will therefore be found most probably in the footwall country rock of the old lead stopes.
2. Zinc ore is especially likely to occur below bodies of hydrated iron oxide situated along the periphery of the primary ore masses—the iron oxide bodies marking the heads of the channels along which the sulphate solutions commenced to migrate into the limestone wall rock. The zinc ore will not necessarily be situated vertically below these masses of iron oxide but may occur diagonally or otherwise as governed by the structural features of the wall rock.
3. Conversely, bodies of lead ore, if not already mined out, may be found on the upward extension of zinc ore deposits, above the iron oxide masses.
4. Zinc ore is likely to be found as far down as the downward limit of the zone of oxidation, the bottom of which has not yet been reached.

The discovery of zinc carbonate ore at Cerro Gordo is another striking illustration of what has been happening in recent years at many of the other silver-lead mining camps in the Western States. Oxidized zinc ores were formerly unsought or were thrown over the dumps unrecognized; only in recent years have they been recognized or their value appreciated. At Leadville the zinc carbonate ores were long unrecognized, but Leadville is now the largest producer of oxidized zinc ore in Colorado; in the Kelly or Magdalena district, in New Mexico, the zinc carbonate ores were long unrecognized, but the Kelly district is now the largest producer of zinc ore in New Mexico; Yellow Pine illustrates the same fact for Nevada; Cerro Gordo illustrates it for California; and according to recent report the abundance of zinc ore in the old stopes at Tintic, Utah, is proving a surprise to the operators there.

These facts render it highly probable that other valuable deposits of zinc carbonate will be discovered in association with galena ore bodies inclosed in limestone, which were formerly worked for their lead and silver. As shown by the occurrence of zinc ore at Cerro Gordo, a fact pointed out in the discussion of the origin of the ore (pp. 106–108), the primary ore bodies need not have contained a large proportion of sphalerite in order to have given rise to commercially important deposits of zinc carbonate.

LEAD-SILVER ORES.

GENERAL CHARACTER.

Argentiferous galena ores occur at a number of localities scattered throughout the region, but only at Cerro Gordo and vicinity has there been a notable production. The ore bodies form irregular lenticular masses inclosed, as a rule, in limestone country rock; in fact, the important productive ore bodies are all inclosed in rock of that kind. Oxidation has partly altered the galena to the carbonate cerusite, and if the ore originally contained zinc blende, the possibility exists that bodies of zinc carbonate ore were formed during the process of alteration, as already discussed in detail under the description of the Cerro Gordo mine.

MINES AND PROSPECTS.

GIBRALTAR PROSPECT.

The Gibraltar prospect is situated 3 miles north of Antelope Spring, in Deep Spring Valley. The prospect was located in 1886, and it is stated that a number of years ago 10 tons of ore was sent to the Selbey smelter; this ore carried $34 to the ton in lead and silver. The country rock at the prospect is a tremolite-bearing white fine-grained marble. The lode trends N. 85° E. and stands vertical. The large open cut on the property exposes a zone about 4 feet wide carrying the small irregular stringers of ore; and 100 feet above is a short tunnel in which the lode ranges from 6 inches to 1 foot in thickness. The ore consists of galena, sphalerite, and tetrahedrite. The oxidized ore shows a little azurite stain, but this is exceedingly rare.

MONTEZUMA MINE.

The Montezuma Mining & Smelting Co.'s property lies near the foot of the White Mountains, 9 miles by road southeast of Big Pine. The Montezuma is one of the old mines of the region and is described in the report of the Director of the Mint for 1883. At that time there was exposed at or near the surface a large amount of argentiferous galena lying almost horizontal. The ore contained 30 ounces of silver to the ton and 38 per cent of lead. A smelter had been built on the railroad at Elna and the ore was hauled there for treatment. This smelter has since been abandoned. It was found later that the ore is difficult to treat on account of its low grade and considerable admixture of zinc blende. The mine was idle during 1912.

Buff-weathering and gray-weathering limestones of dense texture, which on fresh fracture are white with a bluish cast, constitute the prevailing country rock in the vicinity of the upper tunnel. As seen within the tunnel the rocks are intensely shattered and broken, and in one drift a porphyry dike, which seems to have been originally a diorite porphyry, was, because of the intensity of dynamic disturbance, kneaded to a putty-like mass and powerfully slickensided. The ore seen on the dump carries finely disseminated galena, sphalerite, and pyrite, together with a few coarse particles of tetrahedrite; the galena and sphalerite occur in approximately equal amounts and are in part intimately intergrown. The gangue in which these minerals are inclosed consists largely of dolomite with which some quartz is associated. The oxidized ore shows azurite, lead carbonate, and iron oxide.

ESTELLE MINING CO.'S CLAIMS.

The Estelle Mining Co., organized in August, 1902, owns 29 claims situated south and southwest of the Cerro Gordo mine. During the last four years the energies of the company have been devoted to driving a crosscut tunnel, now 4,400 feet long, with the intention of undercutting the iron oxide cropping on the Morning Star claim, which is situated 1,700 feet above the portal of the tunnel. The tunnel, known as the Dellaphene, intersects Carboniferous rocks consisting mainly of limestones. A considerable number of fault zones have been encountered, the most extensive being 200 feet in width. At 3,750 feet from the portal drifts have been turned off both north and south for several hundred feet along one of these fault zones. This fault zone is traversed by a number of quartz veins of irregular size and description. Locally the quartz contains tetrahedrite, galena, sphalerite, and pyrite in amounts in the order named. The ore is said to carry 20 ounces to the ton in silver. The outcrop on the Morning Star claim, which the Dellaphene tunnel is projected to undercut, is said to assay $14 in gold and 17 ounces in silver to the ton across a width of 45 feet. The developments on the Morning Star claim consist of a tunnel 420 feet long, from which a winze has been sunk 225 feet, giving a total depth of 500 feet below the apex. From this winze levels have been run at depths of 35, 70, 120, and 220 feet. A crosscut tunnel traverses what may be called the ore-bearing zone, exposing 35 feet of hydrous iron oxide and limestone, 60 feet of limestone, and then 20 feet more of limestone stained with iron oxide. The iron oxide contains a few small lumps of galena.

MONSTER MINE.

The Monster mine, discovered in 1907, is situated on the east flank of the Inyo Range northwest of Saline Valley. It is reached either by a trail over the summit of the mountains from Mazourka Canyon or by the Saline Valley road from Alvord. The principal developments consist of two tunnels and a number of open cuts.

The general country rock consists of a stratified series of limestones, probably of Ordovician age, striking N. 75° E. and dipping steeply to the north. Several hundred yards south of the mine occur dark knotted schists, representing thermally metamorphosed argillaceous sediments, intruded by granite.

The ore body at the point of discovery was an irregular lens of nearly solid galena 3½ feet wide and approximately 40 feet long. The general trend of the body of ore as seen in the upper tunnel, which is 75 feet long, is northwest. The galena has been nearly completely removed, but at the far end of the tunnel some galena remains embedded in quartz veinlets reticulating through the limestone. The ore makes in bunches in the limestone but is everywhere associated with quartz, although the galena tends to segregate and form pure masses. A new tunnel was driven below the upper tunnel and is approximately 150 feet long, but not much ore was encountered in it. At the portal of the lower tunnel the country rock is a mottled blackish limestone transfixed by tremolite fibers; the rock is coarsely brecciated throughout the length of the tunnel. The limestone in the ore-bearing zone is a buff-weathering variety which is white with a slight yellowish cast on fresh fracture; it is severely brecciated.

The ore seen on the dumps consists almost entirely of galena. It contains a very subordinate proportion of pyrite and even less tetrahedrite, which is to be found only on close search; no sphalerite or other zinc mineral was noted. The oxidized ore consists largely of cerusite, in places finely crystallized, but shows also a little chrysocolla and blue and green basic sulphates of lead and copper—linarite and caledonite.

The ore was taken on pack animals over the Inyo Mountains to Mazourka Canyon, where it was hauled by team to the railroad at Citrus. It was carefully sorted and is reported to have carried $100 a ton in silver and lead. The property was not worked in 1912.

GOLD ORES.

GENERAL CHARACTER AND OCCURRENCE.

The gold deposits of the Inyo and White mountains are mainly small, narrow quartz veins. The greatest depth attained on any of the veins, so far as known to the writer, is 300 feet. The surface ores are thoroughly oxidized and are of comparatively high grade, ranging from a few dollars up to $100 a ton. The mineralogic features are simple; the primary ores carry a small amount of sulphides, commonly pyrite or galena, with subordinate sphalerite and chalcopyrite, inclosed in a coarse white quart gangue. Primary barite was noted in one ore.

The veins occur either in the borders of the granite intrusions or in the surrounding country rock at no great distance from the granite This is so uniformly true that it suggests strongly a genetic connection between the veins and the granite.

A large number of veins have been found and developed, have contributed their quota to the output of the region, and are now exhausted. During 1912 opportunities were not favorable for the study of this class of deposits; consequently a more extended treatment of them here is not advisable, and the details concerning the mines and prospects that were accessible must be sought under the special descriptions.

Many of the deposits were discovered by Mexicans in the sixties and worked by means of arrastres during the succeeding decades. The most important gold-producing area was probably the Beveridge district, on the summit of the Inyo Mountains northeast of Lone Pine. The Keynote, situated at an altitude of 10,000 feet at a point accessible only by a mule trail, was the most productive mine; for a time its output exceeded $10,000 a month.[1] Much ore was taken out from other mines, but records of production are not available.

As a whole the veins have not, however, given rise to a steady gold-quartz mining industry, and during 1912 the exploitation of this kind of ore was nearly at a standstill. The Reward, the largest gold-quartz mine in the range, was idle during the year, pending change of ownership.

Placers, especially those of Mazourka Canyon, were formerly of some importance.[2] The gold was separated by passing the gravel through dry washers. The best ground has been exhausted, and in 1912 a few men working on the rims of the auriferous channels and at the heads of the gullies were able to make only bare wages by dry washing.

MINES AND PROSPECTS.

GOLDEN SIREN PROSPECT.

The Golden Siren prospect is situated in the White Mountains at an altitude of 10,500 feet, near the head of North Fork of Crooked Creek. The main shaft is reported to be 90 feet deep, intersecting

[1] Rept. Director of the Mint upon the production of the precious metals in the United States for the calendar year 1883, 1884, p. 159.

[2] Thirteenth Ann. Rept. California State Mineralogist, 1896, p. 182.

the vein at 45 feet. The country rock is a white marble of Cambrian age, which is intruded by the granite outcropping a few hundred feet east of the shaft. The ore is of two kinds—quartz and iron oxide. The vein sampled over a width of 5 feet is said to average from $14 to $18 a ton in gold.

BLIZZARD EXTENSION PROSPECT.

The Blizzard Extension prospect, which is a scant 3 miles south of the Golden Siren, is situated on the north flank of Mount Blanco at an altitude of 10,800 feet. The developments consist of an incline and a few small open cuts; the incline is 60 feet long, and a drift, 26 feet long, was driven at a depth of 45 feet. The geologic features are essentially like those at the Golden Siren. The country rock is a white marble of Cambrian age, and a large mass of intrusive granite lies a few hundred yards north of the property. The vein strikes N. 80° E. and dips steeply south. It consists, as seen at the surface, of 3 to 6 inches of quartz carrying oxidized sulphides, but it is said to be 2 feet wide in the drift and to average $13 a ton in gold. On the dump considerable gossany iron oxide has accumulated; much of this material was doubtless formed by the reaction of iron-bearing solutions (derived from the oxidation of the primary sulphides originally inclosed in the quartz) on the limstone wall rocks.

During 1912 a road 5 miles long was being constructed to Roberts's ranch, on Wyman Creek, at an altitude of 8,200 feet. Here a small stamp-milling outfit, to be driven by an overshot wheel, was being installed.

WATERFALL PROSPECT.

The geologic features at the Waterfall prospect are unlike those seen anywhere else in the White and Inyo mountains. This prospect, located in 1906, is situated at an altitude of 7,400 feet, 3 miles north of Antelope Spring, in Deep Spring Valley. The general limestone country rock lies within the zone of contact metamorphism of the near-by intrusive mass of granite, and as a result has been considerably altered, chiefly by marmarization and the development of tremolite and other minerals. The gold-bearing deposit, as shown by open-cut workings, consists of a belt of tremolitic white marble traversed by fluoritic veinlets. The fluorite is of pronounced purple color and imparts to the gold ore an unusual and striking appearance. The veinlets range from a fraction of an inch to several inches in thickness. The larger veinlets are quartzose and contain coarse orthoclase, muscovite, and fluorite, and are therefore pegmatitic in composition and appearance. The belt or zone traversed by these veinlets trends north and south and is between 10 and 20 feet thick. The hanging wall is a stratum of black micaceous hornfels. The purple fluoritic ore is said to assay $18 a ton in gold. Neither gold nor other metallic mineral is visible, except rare specks of pyrite. The proportion of fluoritic veinlets to the whole mass of limestone traversed by them is small, and at one point only are the veinlets possibly numerous enough to bring the whole mass up to ore grade.

GRAY EAGLE PROSPECT.

The Gray Eagle prospect is situated on the south side of Redding Canyon, on the west flank of the White Mountains, at an altitude of 7,000 feet. The vein, which occurs at the contact of the granite and limestone, lies nearly horizontal and has a maximum thickness of 8 inches. The quartz carries considerable iron oxide; the sulphide ore shows some chalcopyrite and pyrite associated with iron oxide in a quartz gangue. At the immediate contact a small mass of oxidized ore was found carrying some galena. In the underground workings massive garnet rock is found at the contact, and also rock showing columnar epidote several inches long. These contact rocks are traversed by small quartz stringers carrying a minor quantity of chalcopyrite.

GOLDEN MIRAGE PROSPECT.

The Golden Mirage prospect lies west of the Gray Eagle at an altitude of 6,450 feet. It comprises a number of workings opened on a quartz vein inclosed in the granite. At the lower open cut is shown 2½ feet of solid milk-white quartz, and the vein is seen to strike N. 20° E. and to dip 40° E. Leached cavities in the quartz indicate the presence of former sulphides, which consisted principally of large cubic crystals of iron pyrite. The vein is irregular in thickness; 2½ feet is the maximum and 1 foot is probably a generous average. The gold content is spotted and is generally highest in the honeycombed rock; it is reported to average perhaps $5 a ton for the whole vein.

X-RAY MINE.

The X-Ray mine is an old property, having been worked by the Mexicans in the sixties. The present owners obtained it by relocation after its abandonment by the former owners. This mine is situated on the west side of Redding Canyon, near the Gray Eagle and Golden Mirage prospects, all of which are now under the same ownership. The vein is inclosed in granite and on the south end, which is near the contact of granite and sandstone, ranges from a fraction of an inch to 8 inches in thickness. In the incline driven on the vein it dips 16° N. and trends N. 70° E. Toward the north end the vein is as much as 1 foot thick, but 3 inches is probably the average thickness. The walls are well defined. In view of its narrowness, the vein is remarkably persistent and continuous. The shoot of ore on the south end is said to be nearly 600 feet long. During 1912 five carloads of ore were shipped from this and the other two claims under the same ownership.

EUREKA MINE.

The Eureka mine is situated on the east side of Owens Valley at the foot of the Inyo Mountains, 9 miles northeast of Independence. The California & Nevada Railroad (Southern Pacific system) passes the mine. The property consists of four patented claims, which were located in 1862, the year following the Kearsarge Pass mining excitement. About 1864 a 20-stamp mill was erected on Owens River, which flows near the property; the river was dammed and a water wheel set up, but within a year the mill burned down. The settlement that sprang up here was known as Chrysopolis, but it has long been obliterated.

The principal developments at the Eureka mine consist of a shaft and a tunnel undercutting the deposit at a depth of 100 feet. The prevailing country rock is a fairly coarse hornblende-biotite granite, which is intersected by a number of dikes of dark fine-grained diorite porphyry. These dikes as a rule are highly schistose, whereas the granite is massive. The dike intersected in the tunnel is 15 feet wide; it is roughly schistose and the inclosing granite is somewhat sheared along the contacts. The dikes in general consist of black fine-grained rock which, owing to the presence of small white feldspars, exhibit an obscure porphyritic texture. Under the microscope the porphyritic feldspars are found to consist of plagioclase and the groundmass to be made up of a fine intergrowth of feldspar, finely flaked biotite, and sericite. A specimen of granite, or, more precisely, quartz monzonite, taken from the bottom of the winze at a depth of 140 feet, was determined microscopically to be composed of plagioclase, microcline, quartz, and biotite, with which are associated considerable secondary epidote and calcite.

The ore body consists of a mass of granite interlaced with quartz stringers lying between two dikes of diorite porphyry, which converge at a narrow angle toward the south. The surface ore is highly oxidized, containing much red and brown iron oxide and showing in places some blue copper silicate, chrysocolla. Coarse gold is not uncommon and is readily panned from the oxidized ore. The ore is sorted and shipped to the smelter; recent shipments are reported to have averaged $77 a ton in gold.

On the present small scale of working necessarily the richer ore alone is taken out. Single stringers are followed, and because of their irregular and discontinuous character this makes mining expensive. Investigations with a view to determining the practicability of mining the whole mass of granite and its included quartz stringers are reported to have been undertaken.

BLACK EAGLE MINE.

The Black Eagle mine is situated on the west flank of the Inyo Mountains at an altitude of 8,300 feet, 4 miles in an air line east of Citrus. The developments consist of a shaft 310 feet deep and a number of levels. The ore body is a narrow quartz vein situated at the contact of granite and limestone but is inclosed principally in the granite. The vein trends N. 70° E. and dips nearly vertical but with a slight inclination to the south. On the third level the total length is 400 feet.

The vein material is quartzose, though carrying a little barite intergrown with the quartz and undoubtedly of primary origin; pyrite is the only sulphide noted and its oxidation has given rise to earthy hematite, limonite, and ferruginous jasper. The ore is usually of high grade; by sorting, a product can be obtained that carries $100 a ton in gold. During the operation of the mine the ore was packed on mules at a cost of $4 a ton to a small steam-driven stamp mill at Willow Springs, 2,800 feet lower down on the flank of the range.

REWARD AND BROWN MONSTER MINES.

The Reward and Brown Monster mines, usually spoken of together as the Reward mine, are the property of the Reward Consolidated Gold Mining Co. The Brown Monster was formerly known as the Eclipse, and the Eclipse mill of six stamps was built in 1870. After change of ownership a 30-stamp mill was erected, which was driven by water power generated by water diverted from Owens River. The mill is reported to have produced $200,000, when the property became involved and was sold under an execution.[1] Subsequently this mill was dismantled and the present mill of 20 stamps was built, situated near the mine openings and connected with them by a gravity tram.

In 1911 the mine and plant were overhauled and an electric transmission line 4½ miles long was constructed across Owens Valley to furnish power. After a short run the mine was closed in the spring of 1912, pending change of ownership.

The Reward mine is favorably situated, being on the east side of Owens Valley and less than 2 miles from Manzanar station on the California & Nevada Railroad.

The working tunnel of the Reward mine, which opens on Reward Gulch, intersects the vein at 750 feet from the portal; from the inter-

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[1] Rept. Director of the Mint upon the production of the precious metals in the United States during the calendar year 1883, 1884, p. 160.

section a level, known as the seventh, follows the vein for a distance of 300 feet. Above the seventh level, which is the lowermost in the mine, are six others, ranging from 300 to 500 feet in length. The workings on the Reward vein are all on the south side of Reward Gulch; those on the Brown Monster vein are on the north side and a short tunnel has been driven to connect them with the main working tunnel of the Reward mine. The Brown Monster vein is developed by an incline on the vein several hundred feet long and by several short drifts to the north.

The country rock in the vicinity of the Reward mine consists of a stratified series of limestones of Carboniferous age; to the southwest of the mine Triassic rocks appear, forming the low hills projecting through the alluvium of Owens Valley. The strata strike in a generally northwesterly direction, but as they have been intensely folded the dips are extremely variable. The folded structure is displayed in diagrammatic perfection on the north side of Reward Gulch; in the bottom of the gulch the strata stand vertically, but near the level of the Brown Monster outcrop they are sharply bent and dip west at an angle of a few degrees.

A few hundred yards east of the mine, at an altitude of 5,000 feet, is exposed intrusive diorite which is part of the great granitic mass making up the western flank of the Inyo Mountains for a considerable distance northward from this locality. In consequence of the intrusion the limestones in the vicinity of the mine have been considerably metmorphosed and are either tremolite-bearing marbles or dense-textured lime-silicate hornstones. Dikes and sills have been injected, one of which is particularly noteworthy because, being easily traceable on the surface, it furnishes an index of the character and amount of the faulting that the Reward vein has undergone; this sill is 10 feet thick and is approximately 50 feet above the vein. A limestone bed 1 foot thick, lying above the diorite sill, has as a result of metamorphism been recrystallized to a coarse-grained aggregate of diopside, tremolite, and calcite.

The Reward vein is approximately conformable to the bedding of the inclosing rocks. The hanging wall, as seen above the outcrop, is a stratum of dark-blue siliceous limestone 5 feet thick; locally it is considerably brecciated. The outcrop of the vein can be traced for a distance of 400 feet south of the gulch; here the vein forks and the branches pinch out abruptly. Near the surface the vein lies nearly flat, but as measured at the face of the lowermost drift it dips 40° NE.; the strike here is N. 40° W. The vein swells and pinches abruptly, ranging from a few inches to 10 feet in thickness; the average thickness is 4 feet.

The ore is a coarse white quartz generally devoid of sulphides. On some of the levels the Reward vein shows large solid bunches of coarsely crystalline galena; other sulphides noted were pyrite, chalcopyrite, and sphalerite, but these are extremely rare, and the total quantity of sulphides constitutes a small fraction of 1 per cent of the ore. Oxidation products occur to some extent—limonite, ferruginous jasper, chrysocolla, cerusite, anglesite, the deep azure-blue linarite, and the bluish-green caledonite, the last two of which are rare basic sulphates of lead and copper.

The Brown Monster vein can be traced more or less continuously for a distance of 1,000 feet northwestward from Reward Gulch. In the underground workings the vein displays the same general features that it shows along the outcrop; in places it is a solid and well-defined quartz vein and in others it is mixed with country rock. In the upper levels the vein dips 25° E., but in depth it steepens and near the bottom of the incline the dip increases abruptly to 50°. The vertical depth attained on the vein is 200 feet.

The ore is a quartz practically barren of sulphides. Locally the quartz carries blebs of pyrite and, rarely, chalcopyrite, galena, and sphalerite. Minerals resulting from the oxidation of sulphides originally present are limonite, which is by far the most abundant, calamine, chrysocolla, and wulfenite, but their amount is small. Well-formed crystals of orange-yellow wulfenite occur in vugs in the quartz at the north incline. In the face of the fifth level the secondary minerals are well shown, constituting replacement products of country rock inclosed in the vein. They comprise calamine in fine radial groups, some of which attain half an inch in diameter, hydrous iron oxides, ferruginous jasper, chrysocolla, and wulfenite.

The underground workings of the Reward and Brown Monster mines are dry and oxidation has extended down to the lowest levels, although the larger masses of sulphides, occurring on the upper levels, such as the bunches of galena in the Reward vein, have escaped alteration.

Considerable ore is exposed in the workings of the Reward mine and is stated to average $12 a ton in gold and silver.

Reward Gulch is eroded along a shear zone 40 to 50 feet wide, the crushed and broken character of the country rock being excellently shown in the main working tunnel of the Reward mine. It is therefore a matter of importance whether the Reward and Brown Monster veins are two distinct veins or are the faulted segments of a single vein displaced about 200 feet horizontally along the line of Reward Gulch. The limestone strata or groups of strata match on opposite sides of the gulch, and the diorite sill previously mentioned, which serves as a more easily recognizable indicator than the limestones, crosses the gulch without essential displacement. The powerfully slickensided country rock encountered in the Reward tunnel is therefore the product of oscillatory movement, and as a further consequence it follows that the Reward and Brown Monster veins are two distinct and independent veins. Faults along which displacement has occurred have, however, affected the veins, as shown along the outcrop of the Brown Monster vein and in the workings of the Reward vein, the dislocations ranging from 1 foot to 6 feet. The faulted blocks have been invariably downthrown on the south side. On the north side of Reward Gulch the diorite sill is cut by two faults, both of which displace the sill 15 feet vertically and produce a fault segment 20 feet long.

Several hundred feet stratigraphically above the Reward vein is a bedded quartz vein 2 feet thick; the hanging wall is limestone and the footwall is a diorite sill. The vein carries a moderate quantity of galena and some chrysocolla. In the main mass of diorite near its contact with the invaded limestone is a quartz ledge 6 inches thick carrying galena. The ore is of similar character to that of the Reward vein and is of interest as establishing the fact that the mineralization took place after the intrusion of the diorite.

BURGESS MINE.

The Burgess mine is situated on the summit of the Inyo Range at an altitude of 9,200 feet. It is reached by a trail from Mount Whitney station and by wagon road from Swansea, but supplies are usually brought in by pack train over the trail. In the mine the rocks strike N. 30° W. and dip 65° W. The vein conforms in strike and dip with the inclosing rocks. These are mainly limestones of Triassic age, and crushed specimens of ammonites are readily found in the limestones north of the shaft. Dikes of diorite porphyry are common in the vicinity of the mine.

The ore is a milky-white quartz carrying galena; by sorting, a product high in gold is obtained. The developments consist of two shallow inclines, the principal one of which was operated by a gasoline hoist. During 1912, however, the mine was idle, though it is said that the owners intend to reopen it.

COPPER ORES.

OCCURRENCE AND CHARACTER.

Cupriferous contact-metamorphic rock occurs in limestone at a number of places where the limestone abuts upon the margin of the intrusive granite west of Mazourka Canyon. In the unoxidized condition this material consists essentially of garnet carrying a small quantity of chalcopyrite, but because of the prevalent oxidation the copper is now present mainly as films and thin veinlets of chrysocolla.

On account of the small extent of garnetization and the trivial quantities of copper contained in them, most of the deposits of this type in this region are not of economic importance.

GREEN MONSTER MINE.

The most notable deposit of contact-metamorphic copper ore is that exploited at the Green Monster mine, situated 1½ miles north of Citrus. The total production of this property, it is reported, is 300 tons of 12 per cent copper ore, carrying $4.50 a ton in gold and silver. In 1912 the property changed ownership, and it was the intention of the new owners to develop it systematically. The developments so far made (1912) consist of a number of open cuts, short tunnels, and drifts.

Geologically the mine is situated at the contact of intrusive aplite and limestone that is probably of Carboniferous age. The aplite, which is a white, even-grained rock of fine texture composed of feldspar and quartz, penetrates the limestone in irregular fashion and has produced considerable metamorphism in the invaded rock, as shown by the formation of garnet masses. At the upper workings of the mine the buckled arch of an anticline is exposed; the west limb, which is the more regular, strikes N. 10° E. and dips 30° W.; the east limb stands vertical.

The copper ore occurs in the garnetized zone; it is highly oxidized, so that the facts concerning its origin and distribution are much obscured. It is associated with iron oxides and occurs in such a form that its presence must be determined by chemical means. Chrysocolla, which is found subordinately, is the only copper mineral definitely recognizable. In the outcrop there is much yellowish-green mineral, to whose prevalence the mine doubtless owes its designation. This mineral is in part earthy in texture, and in part shows a fibrous, woody structure. Some of this fibrous material was investigated chemically by W. T. Schaller and proved to be a hydrous ferric silicate analogous to chloropal.

THE ORE DEPOSITS OF KIRWIN, WYOMING.

By D. F. Hewett.

INTRODUCTION.

In comparison with the other States the Rocky Mountain region of Wyoming contains few metalliferous mining camps. Moreover, not many of those that have been started have survived the initial period of develoment, and consequently the metalliferous production of the State, except that of iron, is small in proportion to that from its other resources. Next to the Grand Encampment district, which yielded a fair amount of copper ore from 1898 to 1908, and the South Pass district, which has a record of producing $450,000 in gold from 1868 to 1872, Kirwin was, until a few years ago, thought to possess possibilities of steady production that made it comparable to many camps in Colorado and other Rocky Mountain States. Since 1907, however, with decreasing activity this hope has faded. With the exception of a few prospects, upon which a little work is done each summer, the district is practically abandoned.

Ore was first discovered in the region in 1890 by Will Kirwin, but the financial depression of the next few years served to retard development until 1902, when vigorous exploration was undertaken by several companies, and the town of Kirwin soon had a population of about 200. The boom culminated in 1904, since when activity has steadily decreased. A snowslide in February, 1907, swept away the boarding house and storehouse of the last operators, and from that time to the present very little work has been done.

As often happens, Kirwin has been the scene of much ill-advised mining practice, with the result that the possible merit of the camp has not been fully demonstrated. Between 12,000 and 15,000 linear feet of tunnels and shafts have been opened, of which approximately 5,000 feet represents three crosscut tunnels. The purpose of these tunnels was to explore, at depths ranging from 500 to 1,500 feet, veins which had not been properly prospected near their outcrops. Although such practice may be justified in localities where the character and extent of the ore shoots are well understood, it is rarely successful in new districts in which the veins and shoots have been but slightly explored. At Kirwin these long tunnels have been abandoned without attaining any definite object.

The following report is based on a week's examination of the district during July, 1912. In most of the underground workings the examination was hindered by water, falls of rock, and bad air, and in the higher prospects by snow. The work was, however, furthered by the hospitality and cooperation of Mr. C. E. Tewksbury, in charge of the operations of the Wyoming Mining & Milling Co., which maintains a crew at work during the summer months.

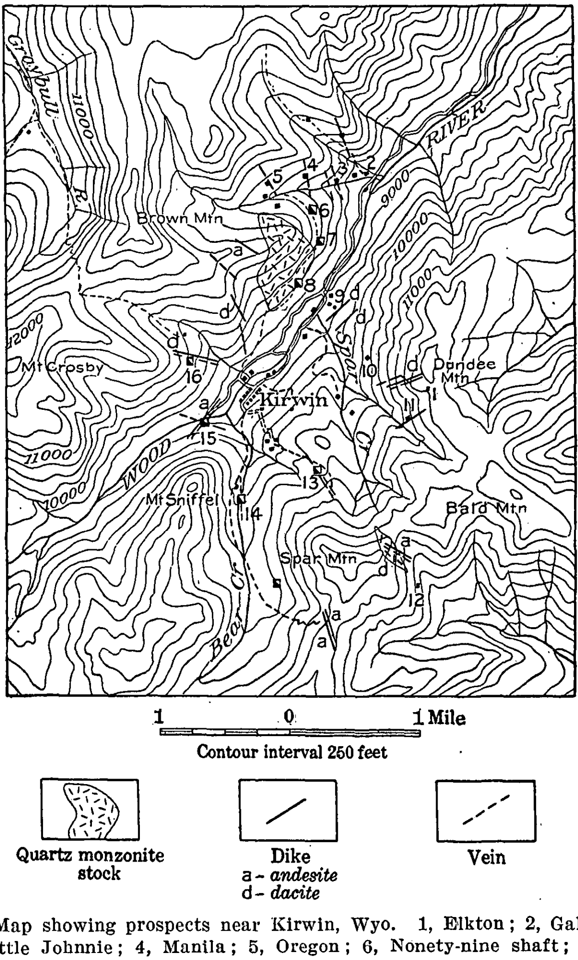

FIGURE 8.—Map showing prospects near Kirwin, Wyo. 1, Elkton; 2, Galena Ridge tunnel; 3, Little Johnnie; 4, Manila; 5, Oregon; 6, Nonety-nine shaft; 7, Ninety-eight shaft; 8, Rose Hannibal; 9, Long Horn tunnel; 10, White Dog; 11, Portland; 12, Smuggler; 13, Bryan; 14, Pickwick; 15, Tumalum; 16, Molly Logan.

SITUATION AND SURFACE FEATURES.

Kirwin is situated near the headwaters of the north fork of Wood River, a tributary of Greybull River, about 38 miles southwest of Meeteetse, Park County, Wyo. During the summer weekly mail service is privately maintained from Sunshine, 15 miles southwest of Meeteetse. Daily stages ply between Meeteetse and Cody, on the

Chicago, Burlington & Quincy Railroad, and Meeteetse and Basin, on the Thermopolis branch of the same road.

The town, now abandoned, lies at an altitude of 9,200 feet, and above it ridges rise precipitously to 12,000 feet. The topographic features of the region are well shown on the Kirwin sheet, published by the United States Geological Survey, of which figure 8 is a partial reproduction. The deep, narrow valley of Wood River is the most prominent feature of the area. The high flat-topped ridges to the northwest and southeast are spurs from the main divide of the Absaroka Mountains, which separates the drainage basin of Wind River on the southwest from the tributaries of Owl Creek and Greybull River on the northeast. This flat-topped character of the ridges throughout the northern portion of the Kirwin quadrangle suggests the previous existence of an extensive surface of low relief, which may be correlated with that which has been recognized in the Bighorn Mountains.[1] The numerous basins in which rise the tributaries of Wood River possess all the features of glacial cirques and many contain perennial snow fields of fair size.

Timber line is well defined and ranges from 10,000 to 10,300 feet; below this altitude the growth of timber is generally heavy and fully sufficient to meet the demands of an active mining industry.

GEOLOGY.

The rocks exposed within the area represented by figure 1 are wholly igneous and constitute a portion of the great thickness of lavas and volcanic breccias that cover several thousand square miles in northwestern Wyoming. These rocks have been studied in detail in the Yellowstone Park[2] and in the region adjoining it on the east.[3] They have been shown to lie upon an eroded surface of folded sedimentary rocks, which range in age from Cambrian to late Cretaceous. In the lower valley of Wood River, 15 miles northeast, the basal beds of the volcanic rocks rest upon sandstones of Wasatch (Eocene) age.

On the basis of his work Hague made a sixfold classification, as follows, beginning at the base: (1) Hornblende andesite breccias, (2) augite andesite breccias and flows, (3) basalt flows, (4) hornblende andesite breccias, (5) augite andesite breccias, and (6) basalt flows. The aggregate thickness of these rocks is approximately 11,000 feet, of which the second group constitutes about 4,000 feet. Though this classification applies to a large area in the vicinity of the Yellowstone Park, Hague points out that at least two members, the first and

[1] Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906, p. 69.

[2] Hague, Arnold, Iddings, J. P., and others, Geology of the Yellowstone National Park, Wyoming: Mon. U. S. Geol. Survey, vol. 32, pt. 2, 1899.

[3] Hague, Arnold, Absaroka folio (No. 52), Geol. Atlas U. S., U. S. Geol. Survey, 1899.

fourth, which contain hornblende in excess of augite, are of minor areal distribution.

The vertical section exposed in the vicinity of Kirwin is approximately 4,000 feet thick and is composed of flows and breccias of several types of andesite. Both hornblende and augite andesites were noted, but the former occur in far greater abundance. By comparison with the sequence recognized by Hague, this section should correspond to the second member of augite andesites, but the relative absence of these types indicates that the section in the region of Kirwin does not strictly conform to that observed 30 miles northwest. Collections of fossil flora from the basal beds of the breccias on Lamar River in the Yellowstone National Park have been determined to be at the base of the Neocene.[1] There is good reason for believing that the breccias in this portion of the Absaroka Range are of the same age.

The section exposed on the east slope of Mount Crosby is composed of flows and breccias, the latter greatly predominating. The breccias are separable according to composition and texture into numerous members which in good exposures appear to have regional dips of a few degrees to the east. Locally members of the group incline from the horizontal as much as 30°, but this attitude is exceptional. The most common variety of breccia contains about 50 per cent of angular to subangular fragments of one or more kinds of andesite suspended in a matrix of a different type, though the fragments locally constitute as much as 90 per cent of the mass. No tuffaceous rocks were found in the section exposed at Kirwin.

The rock penetrated by the Tumalum shaft at the base of Mount Crosby has been examined in thin section under the microscope. Three-fourths of the mass is pale-green andesite porphyry with numerous small white phenocrysts of feldspar and many patches of green epidote, and one-fourth consists of angular fragments of pale-purple andesite, ranging from half an inch to 2 inches in diameter. Under the microscope the matrix contains abundant sodic labradorite, both in angular grains and terminated crystals, here and there largely replaced by epidote, minor amounts of chlorite resulting from the alteration of hornblende, and traces of green glass. The fragments contain predominant sodic labradorite, a little of which has been altered to epidote and calcite, traces of biotite, chloritized hornblende, apatite, and glass. The texture of both rocks is porphyritic. The relationship here observed, in which the matrix contains abundant epidote while the fragments are relatively fresh, prevails throughout the district. Alteration of this type is essentially that known as "propylitic," which occurs in many mining districts in the extrusive andesitic rocks of the Western States. Fragments of a

[1] Hague, Arnold, Yellowstone Park folio (No. 30), Geol. Atlas U. S., U. S. Geol. Survey, 1896, p. 2.

dense white latite are common on the south slope of Mount Crosby. At an altitude of 10,400 feet on the east slope of Mount Sniffel there are two zones of limestone breccia, 5 to 20 feet thick. The fragments are angular to subangular and if they were transported by water can not have moved far from their source.

The breccias are cut by intrusions of two classes, dikes and stocks, which constitute, however, a very small portion of the surface of the district. The dikes range from dacite porphyry, in which the minerals in order of abundance are sodic labradorite, hornblende, quartz, biotite, magnetite, and apatite, to typical hornblende andesite porphyry, in which quartz and biotite are absent. Altogether 12 dikes were observed, though there may be more in the outlying portions of the area covered by figure 8, as these were not examined in detail, and the discrimination of these masses from the breccias requires close examination of the surface.

The second class of intrusion is represented by a single example, the stock on the east slope of Brown Mountain. This stock is composed of a light-gray granular rock which under the microscope is determined to be quartz monzonite. The proportion of the mineral constituents varies greatly from place to place within the mass. Specimens from the north end contain plagioclase in excess of orthoclase in the ratio of 2 to 1 and augite greatly exceeding hornblende, whereas those from the center and southwest portion contain these minerals in practically the reciprocal proportions. Quartz, biotite, and magnetite are relatively constant throughout, and zircon and apatite are accessory minor constituents.

The only evidence of more than one period of intrusion in the district lies in the association of two dikes on the east slope of Spar Mountain. At this point a narrow dike of hornblende andesite porphyry intersects and is hence more recent than a large dike of dacite porphyry. There is no evidence that this relation prevails throughout the district.

No dikes of basic rocks were seen in the district.

ORE DEPOSITS.

The ore deposits at Kirwin exemplify the transition between two types, the dominance of the characteristics of one or the other being approximately in proportion to the size of the deposit. The smaller deposits are fillings of simple fractures or fissures accompanied by slight alteration and metallization of the wall rocks; the larger deposits are narrow fracture zones or groups of fractures, several of which, though usually the outer pair, contain the greater portion of the metallic minerals. In the larger deposits the brecciated rock between the walls is locally silicified and contains small quantities of disseminated metallic minerals. There is, moreover, every transition from relatively unmineralized fractures or sheeted zones to those veins which contain enough metallic minerals to encourage exploration. Replacement of the rock beyond the walls by metallic minerals is uncommon and unimportant. Structurally the deposits are essentially similar to those that have been termed "lodes" in the Silverton district, Colorado,[1] to which this district is in many ways similar.

In some places in the district the rocks over several acres are stained with limonite that is not related to definite fracture zones or veins. The largest of these areas lies at an altitude of 10,000 feet on the west slope of Dundee Mountain and has been explored by two tunnels. The breccias are silicified and, though there is much disseminated pyrite, no well-defined veins have been found.

The courses of the sheeted zones are, with but few exceptions, nearly rectilinear, and figure 9 shows the directions of those which have been recognized during this examination. In this summary only zones having an areal extent in excess of several acres have been included. Of nine sheeted zones, eleven dikes, and eighteen veins which were found, eight zones, six dikes, and eleven veins coincide within 5° of three planes, (1) N. 15° W., dipping steeply east; (2) N. 60° W., dipping 75° NE.; (3) S. 70° W., dipping 80° N. In considering the significance of an apparent coincidence of these directions it must be recognized that the number of observations is small, and that there is a probability that all the veins and dikes are not known; further, that joint systems are in places relatively local and elsewhere relatively extensive, hence there is a tendency to give undue weight to the less widespread systems.

As bearing on the relative age of the stock, joint systems, dikes, and veins it should be noted that one vein has been explored in the monzonite stock and that the mass is extensively fractured parallel to two of the joint systems. Furthermore, the large dike on Spar Mountain is intersected by two veins (Smuggler) and a smaller dike, whereas the other dikes, though superficially much fractured, fill joints of the systems mentioned and are not intersected by them. At least one vein, the Tumalum, is intersected by a dike, and the exploration of each of four others has shown the presence of a parallel dike in one of the walls.

The simplest inference consistent with these observations is that there were at least two general periods of intrusion, between which extensive joint systems were established and veins formed. It should be remembered, however, that the simplest interpretations in the geology of ore deposits are seldom complete and may be highly misleading. The conclusions are stated merely to indicate probable relationships.

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[1] Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, p. 44.

These fissures are obviously relatively simple, and it is interesting to note that in the Silverton district, according to Ransome,[1] "the massive lavas and indurated flow breccias seem to have a general tendency toward relatively simple fissuring, such as results in fissure veins of moderate size and regularity or in sheeted zones."

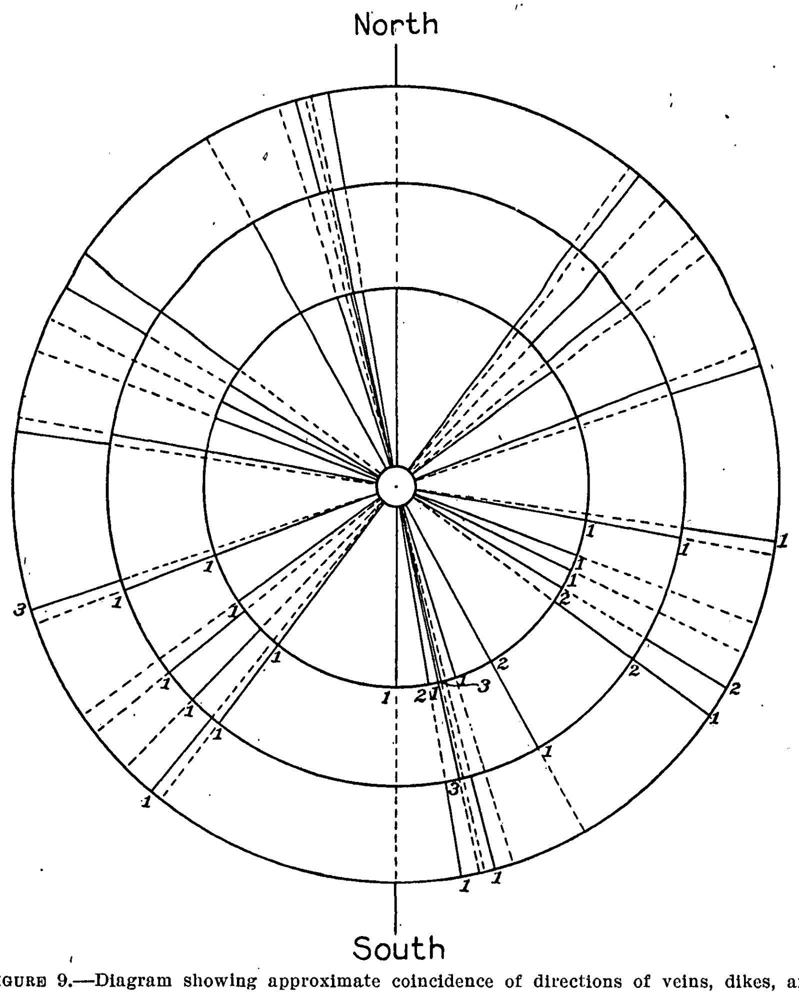

FIGURE 9.—Diagram showing approximate coincidence of directions of veins, dikes, and important sheeted zones near Kirwin, Wyo. Observations indicated by full lines. Veins in inner circle, dikes in middle circle, sheeted zones in outer circle. Figures show number of observations.

No evidence that would suggest the presence of extensive faults in the district has been observed.

The veins, with few exceptions, outcrop in local depressions in the ridges and are not conspicuous, though marked in places by iron oxide stains and copper carbonates, especially malachite. The walls, as a rule, are well defined and bounded by a thin selvage, and the

[1] Ransome, F. L., op. cit., p. 54.

distance between them ranges from a few inches to a maximum of 4 feet. Between the walls there is usually one and in some places two bands of sulphide minerals, ranging in width from 1 to 14 inches, which tend to follow one or both walls, as the case may be. The sulphide minerals either show crustification, indicating growth in open spaces, or are disseminated in minute grains in such a manner as to indicate replacement of the breccia. Locally the relation of the sulphides indicates that one has been formed later than another, either by filling many minute fractures in the grains or the spaces between grains or by replacement of the fractured minerals.

The following minerals were identified in the unaltered portions of the veins of the district, the order being approximately that of the abundance in which they are found; Pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, molybdenite, stephanite, and specular hematite. The minerals found in the superficial or oxidized zone are limonite, malachite, azurite, cuprite, and native gold. Quartz, locally of the amethystine variety, is the principal gangue mineral, though calcite, dolomite, siderite, and barite are present in most of the veins. Adularia was not noted, but as it is a prominent constituent of some of the veins of the Sunlight district, 40 miles northwest, which possess many features in common wth those at Kirwin, it may be sparingly present. The proportion in which the sulphide minerals occur in the veins varies greatly throughout the district. It ranges from as much as 95 per cent in the Pickwick vein, where pyrite is the only sulphide, to less than 5 per cent in the Oregon vein, where sulphide minerals occur in approximately the ratios sphalerite : galena : pyrite = 10 : 3 : 2, with traces of chalcopyrite.

Observations of hand specimens of material from several of the veins, collected both underground and from dumps, suggested that some of the minerals were not deposited contemporaneously with others that constituted the greater portion of the vein. With a view to interpreting the order in which the minerals were deposited in these veins, several polished sections of material from the veins have been examined in detail under the microscope. A typical specimen from the Bryan No. 3 vein is reproduced in figure 10, *a*, and shows an area of relatively pure chalcopyrite adjoining another composed of grains of pyrite with a minor amount of quartz in which there are many minute veinlets of chalcopyrite. The area of chalcopyrite contains many minute round grains of pyrite, in places grouped in clusters, whereas in the other area chalcopyrite either tends to envelop pyrite fragments completely or occurs as a network of minute veinlets penetrating large grains of pyrite. These relations suggest that the clusters of round grains represent the residuals of larger pyrite grains which have been almost completely replaced by chalcopyrite and that this replacement has been incomplete in the adjoining area. They also suggest the inference that, here at least, chalcopyrite was formed at a period distinctly later than the pyrite. Underground conditions, unfortunately, did not permit detailed observations bearing on the economic significance of these features. The chemical formula of chalcopyrite is $CuFeS_2$, whereas pyrite is FeS_2. When chalcopyrite replaces pyrite there may be mere addition of one atom of copper to the pyrite molecule, in which case there will be an increase in volume of 81.7 per cent, or there may be addition of copper with the corresponding loss of iron and sulphur. If a fractured grain of pyrite, such as is shown in figure 10, *a*, were replaced by chalcopyrite by the addition of copper to the free surfaces without corresponding solution of a portion of the pyrite, there should be evidence of an increase in volume, such as the swelling of the outer fragments away from the mass. The absence of any evi-

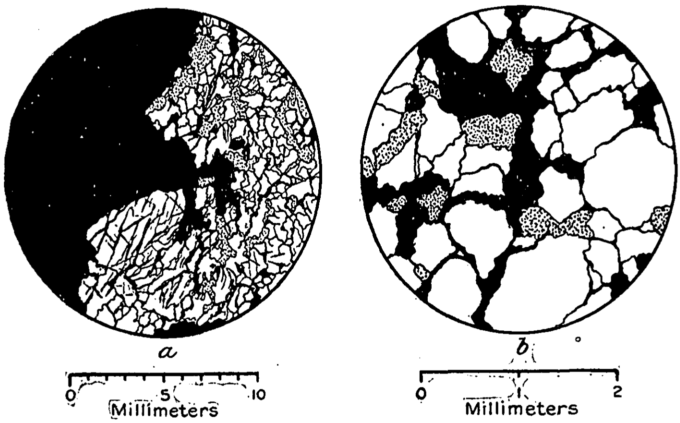

FIGURE 10.—*a*, Specimen from Bryan No. 3 vein, showing chalcopyrite (black), pyrite (white), and quartz (stippled). *b*, Specimen from Tumalum vein, showing pyrite (white), tetrahedrite (black), and quartz (stippled).

dence of increase in volume shows that increase in volume caused by the replacement of pyrite by chalcopyrite has been accompanied by solution of a corresponding volume of pyrite. The specimen is a good illustration of replacement not involving change in volume.[1]

The Tumalum shaft is filled with water, so that it was not possible to examine the vein. In the material on the dump two distinct types of mineral associations were found. One type, which is illustrated by most of the material, shows an aggregate of fragments of pyrite and quartz, the interstices of which are filled with tetrahedrite. (See fig. 10, *b*). Many of the fractured grains of pyrite have clearly been broken from grains of corresponding shape near by. None of the pyrite grains show the network of fractures which would be a feature of replacement, and there is no evidence that this process has taken place. A few of the pyrite fragments contain minute grains of

[1] See Lindgren, Waldemar, The nature of replacement: Econ. Geology, vol. 7, 1912, p. 534.

galena, and there is a little chalcopyrite associated with the tetrahedrite.

The second type of association shown on the Tumalum dump is that of galena with sphalerite and pyrite. Galena tends to completely envelop both aggregates of pyrite grains and small masses of sphalerite and to fill many of the interstices between the pyrite grains as well as fractures in the sphalerite. The associations indicate the deposition of galena in minutely fractured sphalerite and pyrite. Material from the oxidized zone of the Little Johnnie vein contains a small proportion of sulphide minerals, pyrite, and chalcopyrite in quartz which in places shows crusted growth. Stephanite occurs as crystals lining and in places almost filling small quartz-lined cavities. The stephanite is clearly the last mineral that was deposited in the vein.

The foregoing observations are obviously isolated and the relations indicated can not be urged to the exclusion of all others, but taken with other observations in the field they suggest certain inferences. In most of the veins of the district the primary ore probably consisted of pyrite with minor amounts of sphalerite and chalcopyrite. In the two veins which have been most extensively developed, the Bryan and Tumalum, the primary minerals have been crushed and a secondary group of sulphide minerals deposited—chalcopyrite in the Bryan No. 3 vein and tetrahedrite and galena in the Tumalum vein. Whether these secondary minerals have been formed by the process of downward enrichment or by ascending deep-seated waters can not be stated. The proof of formation by downward enrichment involves data which are not available,[1] but it is at least possible that the second period of mineral deposition in the Tumalum vein is related to a second period of intrusion of dikes, as previously indicated. This does not appear to be the cause of the stephanite of the Little Johnnie vein, which is probably due to downward enrichment.

In only four places in the camp has sufficient work been done to demonstrate with relative assurance the horizontal extent of an ore shoot, these being Bryan, Pickwick, Tumalum, and Oregon. In only one of these, the Bryan, has the vein been explored sufficiently on more than one level to determine even approximately the limits of a shoot, so that it is evident that only the most general statement can be made about the attitude of the shoots in the vein. The horizontal extent of the shoots ranges from 50 to 250 feet, and the Bryan shoot coincides with the dip of the vein.

The value of the ores in the district lies mainly in the gold content, and only rarely in silver. No assays have been made in connection with this examination. Information placed at the writer's dis-

[1] Ransome, F. L., Criteria of downward enrichment: Econ. Geology, vol. 5, 1910, p. 205.

posal by Mr. C. E. Tewksbury indicates that selected material from some veins has yielded 200 ounces of silver a ton and from others 15 ounces of gold a ton, though such results must be regarded as exceptional. It is doubtful if the average tenor of any vein is even approximately known, for there has been very little stoping. The only shipment known to have been made from the district was a carload taken from the upper or No. 2 Bryan tunnel and is reported to have yielded a net return of $65 a ton after all transportation and smelting charges had been deducted.

PROSPECTS.

The most ambitious project of the district is the Galena Ridge tunnel, 2,327 feet long, for the driving of which compressed air drills and electric haulage were installed. Bad air prevented access in 1912. The tunnel is reported to have cut the Little Johnnie vein explored on the surface and some other small veins. No drifts were run on the veins from the tunnel level.

The Bryan vein is opened by tunnels 1, 2, and 3, which are 80, 480, and 880 feet long, respectively. From the lowest tunnel there are also about 1,200 feet of drifts. Four veins were cut, two of which have been explored. Vein No. 3 attains a maximum width of 4 feet and at its widest part contains two bands of sulphide minerals, which were estimated to constitute 15 per cent of its bulk. Vein No. 4 is a simple filled fracture and attains a maximum width of 10 inches, between well-defined walls. The sulphide minerals were estimated to exist in approximately the proportions pyrite: chalcopyrite: sphalerite=20:5:1, with traces of galena and molybdenite.

The Pickwick vein has been explored by a crosscut tunnel 610 feet long from which a drift follows the vein for 300 feet. The vein is a simple fracture filled with pyrite, and has a maximum width of 14 inches. Ruby silver (proustite) is reported from surface workings, and silver is said to have constituted the principal value of the vein material.

The workings of the Tumalum vein are filled with water, but are stated by Mr. Tewksbury to comprise a shaft 250 feet deep, from which drifts extend 230 feet east along the vein. The vein in places is 4 feet wide and contains pyrite with small amounts of galena, sphalerite, chalcopyrite, and tetrahedrite. Assays as high as $90 a ton in gold are reported.

The Molly Logan tunnel is not accessible on account of bad air, but is reported to be 1,400 feet long. It was driven in the hope of cutting a vein which was explored on the surface 600 feet higher, but was abandoned without attaining that object.

The Oregon vein is opened by a tunnel 340 feet long. It ranges from 4 to 20 inches in width between well-defined walls and contains sphalerite, galena, and pyrite in the proportion 10:3:2, with traces of chalcopyrite. The gangue is siderite and quartz. Selected ore is reported to have contained as much as 200 ounces of silver a ton.

The Long Horn tunnel has recently been driven by the Wyoming Mining & Milling Co. In July, 1912, it was 1,170 feet long, but no veins had been cut.

There are a number of other short tunnels and shafts in the district, most of which were wholly or largely inaccessible on account of caves, water, bad air, and snow. None appear to have explored veins notably different from those described.

COMPARISON WITH OTHER DISTRICTS.

Spurr,[1] in the report upon the Tonopah district, has pointed out that a number of mining districts throughout western North America have several features in common. These features are kind of country rock, age and structure of veins, vein minerals, and character of rock alteration. The Kirwin district belongs to this group. The similarity, however, as is unfortunately often the case in metalliferous districts, is qualitative rather than quantitative and is by no means to be construed as implying the existence of ore bodies of similar size and richness in each of the districts. Compared to many of these districts, of which only a few are mentioned by Spurr, Kirwin is characterized by fewer and smaller intrusive rock masses, by less complete and less extensive rock alteration (in some of the districts, such as Silverton, alteration is locally marked), and by narrower and less persistent veins in which the ore shoots appear to be relatively small. The absence of extensive metallization at Kirwin may be due in part to the absence of large intrusive masses of siliceous igneous rocks.

FUTURE OF THE DISTRICT.

The region in which Kirwin lies is difficult of access, and owing to its scanty natural resources there appears to be little reason for anticipating better transportation facilities in the near future. From what is to be seen in the district it seems unlikely that there will be developed masses of low-grade ore large enough to warrant the installation of elaborate milling plants. The only ores that have thus far been produced are of medium or high grade, but in quantities too small to warrant costly equipment or operation on a large scale.

Mining, however, is full of uncertainties and it would be unsafe on the basis of a brief examination to predict that none of the Kirwin deposits will ever prove to be important.

[1] Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 267.

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. A list of publications on Alaska is given in Bulletin 542, the annual report on the progress of the Survey's investigations in Alaska for 1912.

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. The publications marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

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COPPER.

COPPER DEPOSITS NEAR SUPERIOR, ARIZONA.

By F. L. Ransome.

INTRODUCTION.

The little hamlet of Superior is in the south-central part of Arizona, in Pinal County. About it centers the present activity of the Pioneer district, in which the first mining locations, the Silver Queen and Silver King, were recorded in 1875. In a straight line Superior is 11 miles northwest of Ray (see fig. 11), but the intervening country is rugged, and Florence, 30 miles distant by road, is the usual point of rail shipment. The group of rough hills and mountains within which the district lies has no generally recognized name, although certain parts, such as the Superstition Mountains, have received distinctive appellations. It constitutes a northward prolongation of what, south of the Gila, is known as the Tortilla Range and it may appropriately be included under the same designation. To the northeast it merges into the Pinal Range and on the southwest it overlooks the lower and more open country around Florence and Phoenix. Superior is on the north bank of the westward-flowing Queen Creek, at the west base of a prominent and precipitous ridge known in part as Apache Leap.

The following notes are the result of only two days spent in the district, a time obviously too short for a thorough investigation of the geology and ore deposits, yet long enough to yield information which it is hoped may be worth recording.

GENERAL GEOLOGY.

The generalized geologic column of the region adjacent to Globe and Ray is shown in figure 12. At the base is the Pinal schist, cut by various pre-Cambrian granitic intrusions, some of which are of wide extent. Resting on the evenly worn surface of these ancient rocks in ascending series are (1) the Scanlan conglomerate, (2) the Pioneer shale, with generally some arkosic sandstone at its base, (3) the Barnes conglomerate, (4) the Dripping Spring quartzite, (5) a cherty dolomitic limestone[1] with a flow of rusty vesicular basalt at the top, (6) an upper quartzite,[1] (7) generally rather thin-bedded limestone with subordinate shale, carrying Devonian fossils, (8) thicker-bedded Carboniferous limestone, (9) andesite, andesite breccia, and tuff, supposedly of Cretaceous age, (10) the Whitetail con-

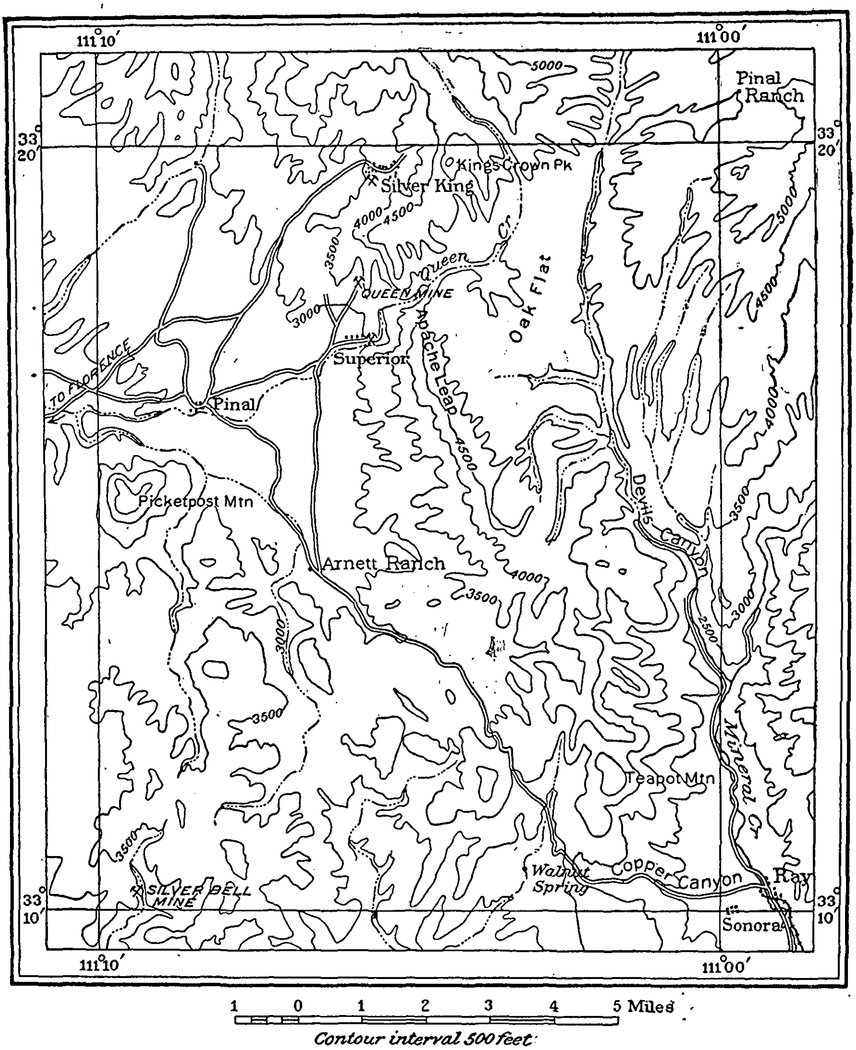

FIGURE 11.—Outline map of Superior, Ariz., and vicinity.

glomerate, a heterogeneous accumulation of imperfectly rounded fragments, probably Tertiary in age, (11) dacite, with some associated tuff, probably Tertiary, and (12) the Gila conglomerate, a thick deposit of variable fluviatile gravels, with local silty facies, probably of early Quaternary age. For full descriptions of these

[1] Names will be given to these formations in a forthcoming report on the geology and copper deposits of the Globe-Ray region.

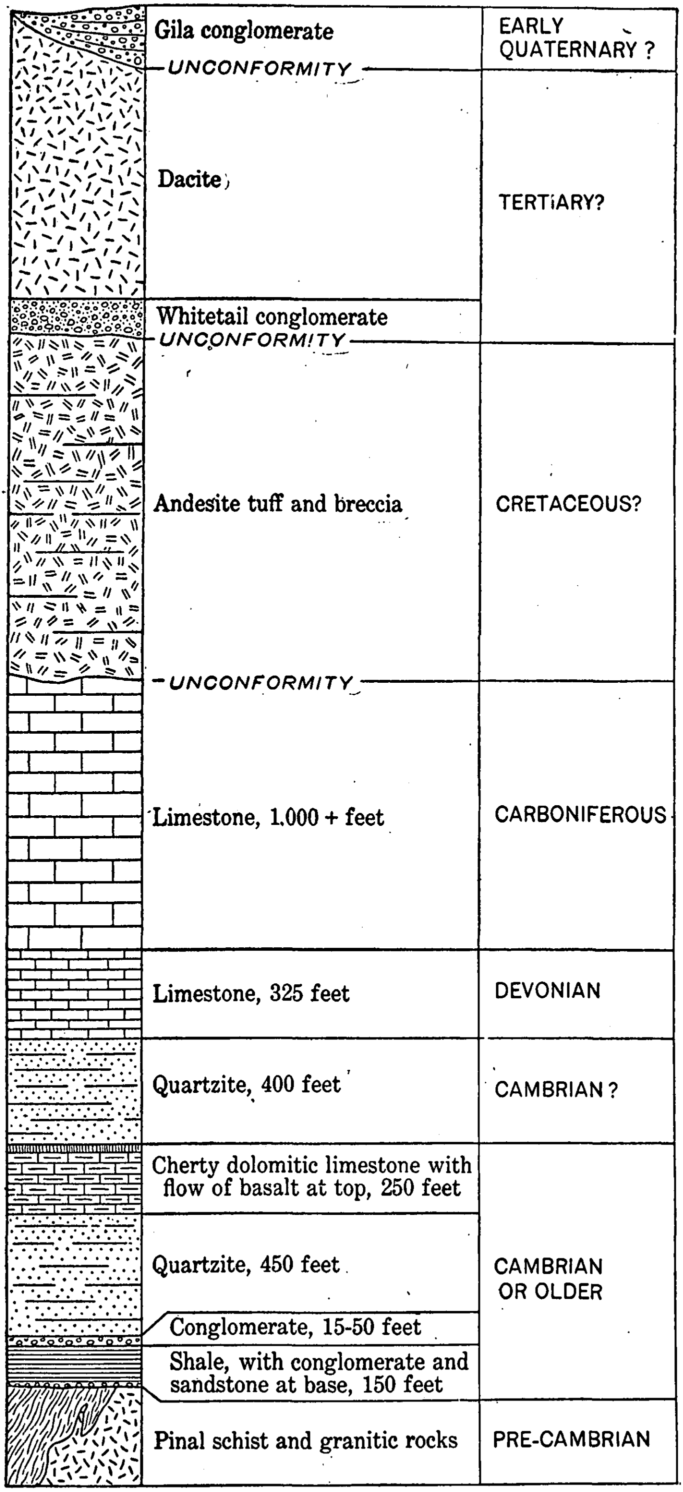

FIGURE 12.—Generalized columnar section for the region adjacent to Ray, Arizona.

formations the reader is referred to the geologic literature on the region.[1]

The age of formations 1 to 6 is not yet definitely known, as they have yielded no fossils within the Globe-Ray region. Without much question they are in part Cambrian, but some of the lower beds may be older than that period and there is a possibility that the upper quartzite may be post-Cambrian. In this part of Arizona no unconformity has been recognized anywhere in the series between the Scanlan conglomerate and the Carboniferous limestone, but reconnaissance work to the north, between Globe and Payson, suggests that one may be present.

In addition to the sedimentary and volcanic rocks mentioned the region contains some post-Carboniferous but pre-Tertiary intrusive rocks. The most abundant of these are diabase, which forms great irregular sheets and masses, especially in the pre-Devonian stratified rocks, and bodies of porphyritic to granular rocks ranging in composition from quartz monzonite or granodiorite to granite. These granitoid rocks are exemplified by the Schultze granite and associated porphyry of the Globe quadrangle, the granodiorite at Troy, and the quartz monzonite porphyry at Ray. They are younger than the diabase and are closely associated with the disseminated copper ores of this region.

The important formations exposed at Superior are, in ascending order, an intrusive sheet of diabase, the upper of the two pre-Devonian quartzites, the Devonian limestone, the Carboniferous limestone, and, finally, a flow of dacite, which forms the crest of Apache Leap and is the prevailing rock over a rough desolate country for 5 or 6 miles to the east. The general dip of these rocks is 35° E. The Devonian here appears to be fully as thick as in the Ray quadrangle and is similar in lithologic character, the uppermost bed being a shale which weathers into small yellowish flakes.

At the almost entirely deserted settlement of Silver King, which lies in a westward-opening embayment in the hills, at the north end of the Apache Leap ridge, 2½ miles north of Superior, the same formations as at Superior are exposed on the inclosing hillsides, but the rock close to the settlement is an intrusive mass of quartz diorite porphyry. This is surrounded by Pinal schist, which appears to occupy a considerable area of the hilly ground to the northwest, and it is intrusive also into diabase, just north of the Silver King mine.

A prominent structural feature near Superior is a strong fault (see fig. 13) which strikes a little west of north. The line of this

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[1] Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903; Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey; Geology of the Globe district: Min. and Sci. Press, June 3, 1911, p. 747. The descriptions in the publications cited will be supplemented by those in the Ray folio, now in preparation.

fault is plainly visible north of the village and passes a few feet west of the Queen mine. The fault plane dips west, apparently at about 60°, and the displacement is normal. By this movement Carboniferous limestone west of the fault has been brought against diabase and quartzite east of it. The dislocation is believed to be younger than the dacite and is probably responsible for the steep west front of Apache Leap. The fault itself is concealed by alluvial deposits south of the Queen mine.

MINES.

The most noted mine in the vicinity of Superior is the Silver King, which was opened in 1875 and for many years produced high-grade silver ore from a deposit of the form commonly called by miners a "chimney." The mine ceased to be regularly productive about 1888 and has been continuously idle since 1898. In 1912 the ground was relocated, on the contention that it had been abandoned by its former owners. The production of the Silver King is variously reported as between $10,000,000 and $15,000,000. The lower figure is probably too high, but the Silver King Mining Co. is known to have paid dividends up to July, 1887, amounting to $1,950,000. The mine was worked through three shafts. The main shaft and large, compact stopes worked by square setting extend to a depth of 800 feet, below which a winze connects with the 950-foot level of the No. 2 shaft, which was used for pumping. The workings are now full of water.

The Queen or Silver Queen mine, about three-fourths of a mile north of Superior, although opened as early as the Silver King, and credited with some production about 1880, has only recently become important through the activity of the Magma Copper Co. The deposit, which occurs along a nearly east-west dike, is opened to a depth of 800 feet, with short levels at 200, 400, 500, 650, and 800 feet below the collar of the vertical shaft. The 200-foot level is merely an adit, 500 feet long, from which hoisting is now done instead of from the collar of the shaft, which is on the crest of the steep spur crossed by the dike. The ore from the Queen mine is hauled in wagons to Florence, two days being required for the 30-mile trip, at a cost of $5 a ton. The return rate on supplies is $7 a ton.

The Lake Superior & Arizona mine has its principal adit, the Carlton tunnel, on Queen Creek a few feet above the stream bed. The tunnel pursues a devious course for nearly 2,000 feet to the north-northwest, following in general the contact between the Devonian limestone and the underlying quartzite. At its north end the tunnel connects with a 26° incline about 1,800 feet long (see fig. 13), from which some short levels have been run along bedding planes in the limestone. The Holt tunnel, at the head of the incline, opens to the surface just north of Superior. This is the most extensively developed mine in the district, but although some oxidized copper ore was found in it, the quantity was discouragingly small, and work

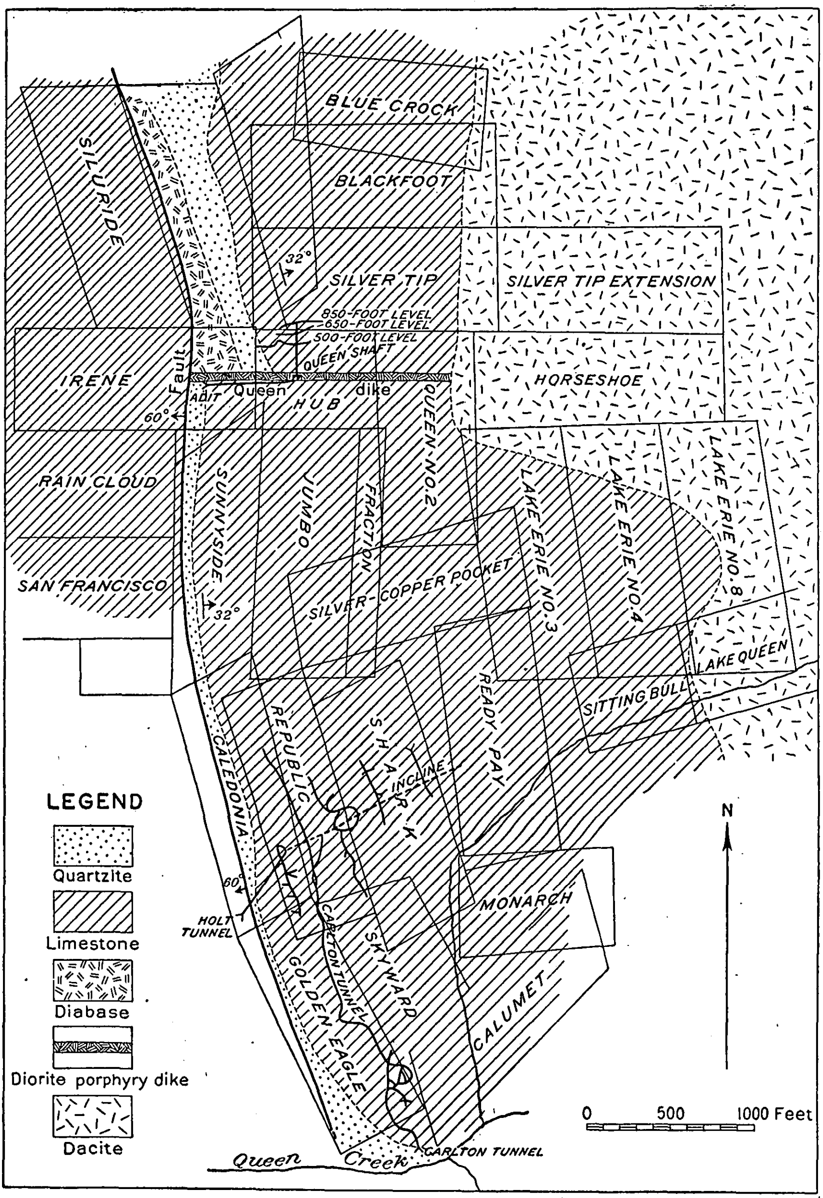

FIGURE 13.—Sketch map showing claims and the general geologic relations of the mines near Superior. From data furnished by the Magma Copper Co.

was abandoned a few years ago. It is reported that since the visit on which this paper is based exploration has been resumed.

SPECIAL FEATURES OF THE ORE DEPOSITS.

FORM AND OCCURRENCE OF THE ORE IN THE QUEEN MINE.

The ore of the Queen mine has been deposited in a nearly east-west dike of porphyry, which is so altered and decomposed that its original character is obscured. Apparently the rock was a rather fine grained quartz diorite porphyry. The width of the dike is variable, but probably nowhere exceeds 40 feet. In places small tongues of the intrusive rock extend into bedding planes, and other minor irregularities are due to slight faults, mostly slips along the bedding of the stratified rocks. The dike dips to the north, generally at 60° to 70°. The beds, which it cuts nearly at right angles to their strike, dip 32° E.

The dike occupies a fault fissure along which the major movement appears to have taken place before or during the intrusion. The movement was "reverse" in terms of fault nomenclature, or, as commonly stated, the footwall went down in relation to the hanging wall. Consequently an observer walking east on a level driven along the dike has on his right hand rocks higher in the stratigraphic column than those on his left. Moreover, in consequence of the general easterly dip of the beds, after he first sees limestone on the right hand, he must continue eastward for 400 to 450 feet before he reaches the same stratigraphic horizon on the left. The dip slip—that is, the component of fault movement that is measured in the fault plane in the line of dip—is roughly estimated as between 500 and 600 feet. By keeping these simple geometric relations in mind the reader will readily understand the following description of the ore bodies. The old work in the Queen mine was confined to ground above the original water level, which stood at a depth of about 400 feet. Some oxidized ore was taken from these upper workings, but it was left to the present company to show that this was insignificant in comparison to the rich sulphide ore below. Too little work had been accomplished in 1912 to place the shape and extent of the ore bodies beyond question, but such data as were obtainable indicated the existence of two distinct pay shoots lying in those parts of the dike where quartzite forms one wall and pitching to the east in the plane of the dike at approximately the same angle as the dip of the quartzite beds. These relations are shown diagrammatically in figure 14, which is a north-south section across the dike in the meridian of the shaft. In the plane of this section part of the upper body has suffered oxidation. As a rule these two prisms of ore are nearly or quite as wide as the dike, may measure 100 feet or more vertically from top to bottom, and, in the line of pitch, extend to depths that had not been determined at the time of visit. Apparently the best ore lies near the upper part of the quartzite, and in some places the dike contains good ore for short distances above the line of intersection of the upper surface of the quartzite with the side of the dike.

CHARACTER OF THE ORE IN THE QUEEN MINE.

The minerals composing the ore of the Queen mine are chalcocite, bornite, chalcopyrite, pyrite, and quartz. The usual oxidation products are found above the original water level and a very little covellite was noted in some of the lower-grade material, said to come from the 800-foot level. The ore is sorted and the better grades, shipped as crude ore, carry from 15 to 35 per cent of copper, with some gold and silver. In 1912 the mine, then just beginning its present period of activity, produced 129 tons of ore averaging 26 per cent of copper and carrying an average content of 0.07 ounce of gold and 0.29 ounce of silver to the ton. In the first-class ore chalcocite and bornite are the principal minerals. These occur as mixtures in various proportions and as nearly pure masses, particularly of chalcocite. The chalcopyrite is less abundant and is generally associated with pyrite, which is almost absent from the best ore.

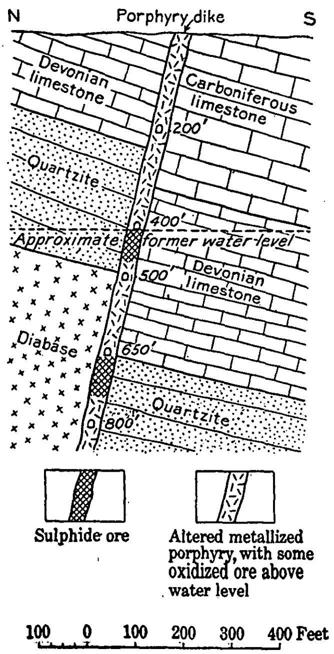

FIGURE 14.—North-south section across the Queen dike, showing the general relation of the ore shoots to geologic structure.

In the richer parts of the ore bodies the substance of the dike has been almost entirely replaced by masses of solid sulphides with comparatively little quartz, and to trace the stages of this replacement it is necessary to study the leaner material, such as is now thrown on the dump. In the least cupriferous material pyrite is the principal sulphide and occurs with quartz in an intricate tangle of veinlets that traverse the porphyry in all directions. The boundaries between the veinlets and the porphyry are not entirely sharp and it is clear that the pyrite and quartz have not only filled the cracks and openings in the rock but have to some extent replaced the porphyry. The gradations between this lean material and ore are twofold, one essentially structural and the other mineralogic. Where the fissures are numerous and in part of considerable size and where consequently the porphyry has been subject to vigorous metasomatic attack at many adjacent points the original material of the rock has been replaced by pyrite with generally rather subordinate quartz and probably a small proportion of chalcopyrite. Mineralogically the pyritic material grades through various mixtures of pyrite, chalcopyrite, bornite, and chalcocite into nearly pure chalcocite. All the sulphides mentioned occur also in disseminated form through the altered porphyry in the vicinity of the fissures.

As seen in place or in ordinary hand specimens, the ore shows only here and there a suggestion that the various sulphides may not be contemporaneous in origin, a suggestion so faint that to the casual observer the ore appears to be a mass of sulphides and quartz confusedly intergrown during a single period of crystallization. The study of polished sections under the microscope, however, reveals a more interesting relation.

The general sequence of the sulphides proves to be pyrite, chalcopyrite, bornite, and chalcocite. The first mineral to be deposited in the fissured porphyry was pyrite. Subsequently this mineral was minutely and irregularly cracked and chalcopyrite was deposited as a mesh of microscopic veinlets in the pyrite. (See fig. 15.) In places the walls of these veinlets are smooth and distinct, but as a rule the outline of the chalcopyrite as seen in polished sections is rough and more or less indefinite. It is clear that many of the original cracks have been enlarged by the metasomatic replacement of pyrite by chalcopyrite. The structure, illustrated in figure 15, appears to correspond to that which L. C. Graton and Joseph Murdoch[1] have characterized as the "exploding bomb" structure.

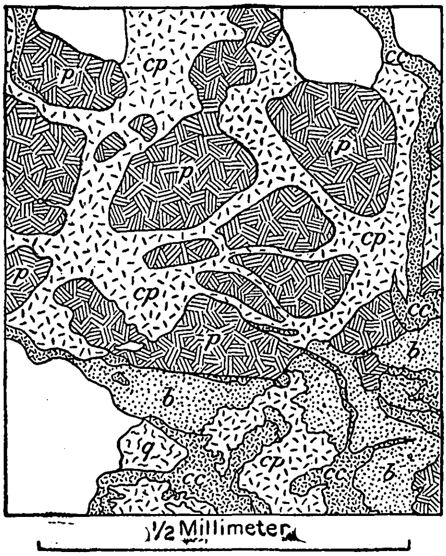

FIGURE 15.—Microdrawing of polished surface of ore from the 800-foot level of the Queen mine. Outlined with camera lucida. *p*, Pyrite; *cp*, chalcopyrite; *b*, bornite; *cc*, chalcocite; *q*, quartz; white area, hole or pit in section.

After the deposition of the chalcopyrite the vein material was again cracked, and many of the fragments were considerably displaced. The resulting cracks and interstices, many of them wide, were filled with quartz, which forms the gangue of the sulphides.

The physical relation of the bornite to the chalcopyrite presents some perplexing features. In many places the two minerals are intimately associated in a structure that is strongly suggestive of

[1] The sulphide ores of copper—some results of microscopic study: Trans. Am. Inst. Min. Eng., New York meeting, February, 1913, advance ed., p. 45, fig. 2.

contemporaneous intergrowth (see figs. 16 and 17), such as has been carefully described by F. B. Laney.[1] No structure seen in the Superior ores, however, has exactly the appearance of ordered irregularity peculiar to a typical micrographic intergrowth such as is illustrated in plate 68 of Laney's paper. Moreover, further search shows that in some places the bornite traverses the chalcopyrite in veinlets that are obviously coincident with cracks. Very rarely, and generally for very short distances, these bornite veinlets may have smooth, parallel sides. As a rule, however, the boundary between bornite and chalcopyrite is very irregular, and all gradations may be found between distinct veinlets of bornite and isolated shreds and particles of bornite distributed thickly through the apparently unfissured chal-

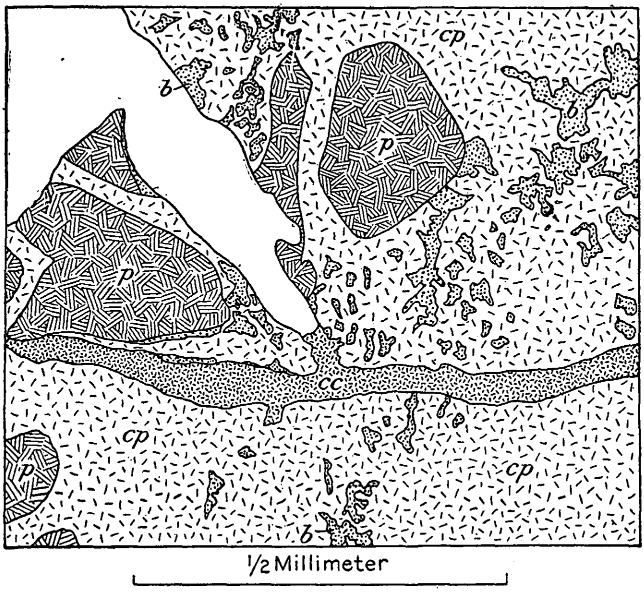

FIGURE 16.—Microdrawing of polished surface of ore from the 800-foot level of the Queen mine. Outlined with camera lucida. Shows remnants of pyrite (*p*), surrounded by chalcopyrite (*cp*) with bornite (*b*) in areas suggestive of intergrowth with chalcopyrite. Chalcocite (*cc*) in a distinct veinlet.

copyrite. There is a similar unbroken transition between the structure in which chalcopyrite is the host mineral and one in which bornite contains only a few scattered particles of chalcopyrite.

Although some of the bornite is thus clearly younger than the chalcopyrite, which it traverses in veinlets and has in part metasomatically replaced, the possibility that there may be two generations of bornite remains to be considered. The only support to this view is the intimate association of some of the bornite and chalcopyrite in apparent intergrowths unconnected with visible fissuring.

[1] The relation of bornite and chalcocite in the copper ores of the Virgilina district of North Carolina and Virginia: Proc. U. S. Nat. Mus., vol. 40, 1911, p. 519, pl. 68.

On the other hand, undoubted replacement veinlets of bornite may be fringed with precisely such apparent intergrowths or may die out as veinlets, to be continued along the same general line by a vague zone of bornite flecks in the chalcopyrite. Finally, the general arrangement of the bornite as a layer intervening between chalcopyrite and pyrite on the one hand and chalcocite on the other, as appears from the study of broad polished faces of the ore, reenforces the conclusion that the bornite is younger than most of the chalcopyrite.

The relation of the bornite to the quartz gangue is not as a rule very clearly shown, but a few of the bornite veinlets in chalcopyrite have a medial sheet of quartz which was the first filling of the fissure. The bornite was deposited later, chiefly by replacement of the chalcopyrite along the walls of the original quartz film. The bornite in a general way shows a pronounced tendency to occur near the periphery of quartz areas as seen in section, but this tendency has been obscured in part by the subsequent development of chalcocite along the same paths at the expense of the bornite.

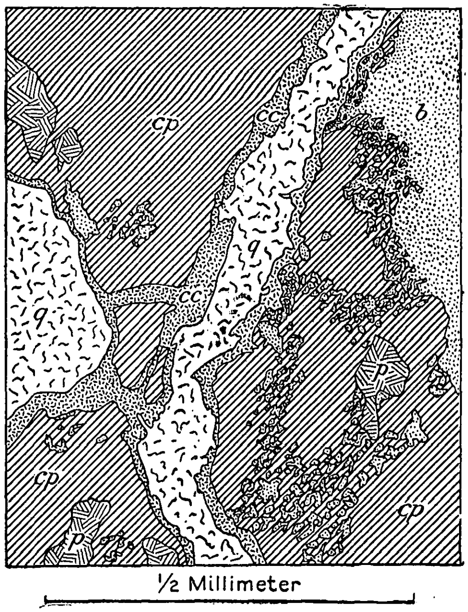

FIGURE 17.—Microdrawing of polished surface of ore from the 800-foot level of the Queen mine. Outlined with camera lucida. Chalcopyrite (*cp*) with residual pyrite (*p*), and younger bornite (*b*). The bornite in part seemingly intergrown with chalcopyrite. A quartz veinlet (*q*) bordered by chalcocite (*cc*).

The relations between chalcocite and bornite are very similar to those between bornite and chalcopyrite. After the deposition of the bornite fresh cracks were opened in the ore. Some of them appear to have been filled by a second and minor infiltration of quartz, although it is not certain that these quartz-filled veinlets do not belong to the earlier and main period of gangue formation. Be that as it may, many fresh cracks were certainly formed in the ore and were filled with chalcocite. Every contact between quartz and sulphides was searched by the copper-bearing solutions, and layers of chalcocite were deposited by replacement of the adjacent sulphide—in some places pyrite, in some chalcopyrite, but in most places bornite. (See figs. 17–19.) This deposition of chalcocite along the contacts between quartz and older sulphides has been noted by Laney[1] and a similar feature in silver ores has been described by E. S. Bastin.[2] Precisely as in the case of the bornite and chalcopyrite so with the chalcocite and bornite; there are all gradations from distinct chalcocite veinlets to apparent intergrowths between chalcocite and bornite. In one part of a polished section the bornite appears full of irregular flecks of chalcocite such as would ordinarily be considered as forming an intergrowth with the bornite; a slight shift of the section may bring into view an alignment of flecks which at once prompts

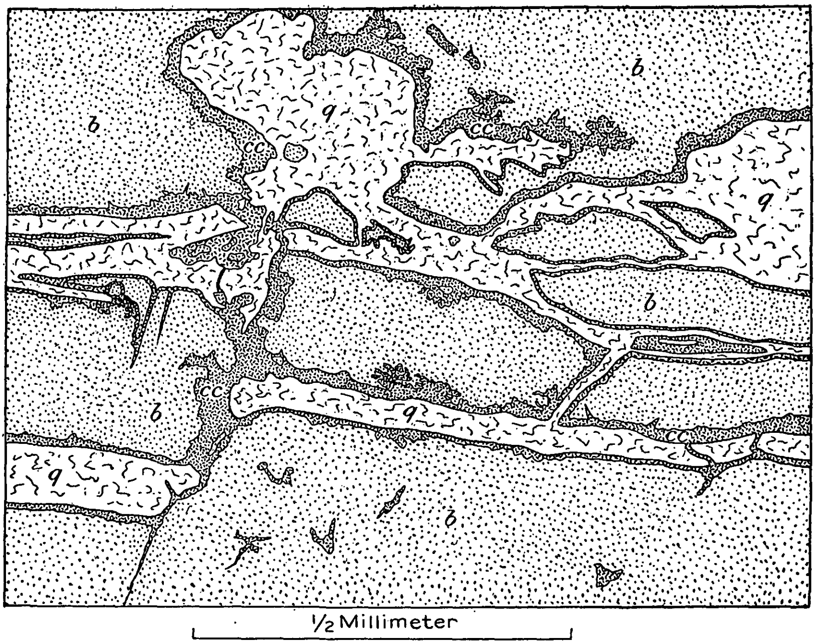

FIGURE 18.—Microdrawing of polished surface of ore from the Queen mine. Outlined with camera lucida. Characteristic irregular quartz veinlets (*q*) bordered by chalcocite (*cc*) which has developed from bornite (*b*).

the suggestion that their occurrence is related to fissuring; and another change in the field may perhaps show the linear zone to pass into a distinct microscopic fissure filled with chalcocite and fringed with an irregular border of the same apparent intergrowth. Even more clearly than in the case of bornite in chalcopyrite, the chalcocite in bornite differs on close inspection from thoroughly typical micrographic intergrowths. The little areas of chalcocite as seen in thin section are as a rule sharply and irregularly acuminate, as if the replacement had begun at the intersection of some very minute cracks and had extended out along those cracks for short distances,

[1] Op. cit., p. 518.
[2] Metasomatism in sulphide enrichment: Econ. Geology, vol. 7, 1913, p. 53, fig. 5.

while here and there are distinct suggestions of replacement along microscopic fractures.

The conclusion appears to be highly probable, if not inevitable, that all the chalcocite is younger than the bornite and that all the bornite is younger than most of the chalcopyrite, the reservation in the case of chalcopyrite being demanded by the existence of a very little chalcopyrite that has been deposited in veinlets with the chalcocite at or about the same time. It follows that in the alteration of the relatively unstable minerals chalcopyrite and bornite to the final stable form chalcocite the change is not limited to the walls of

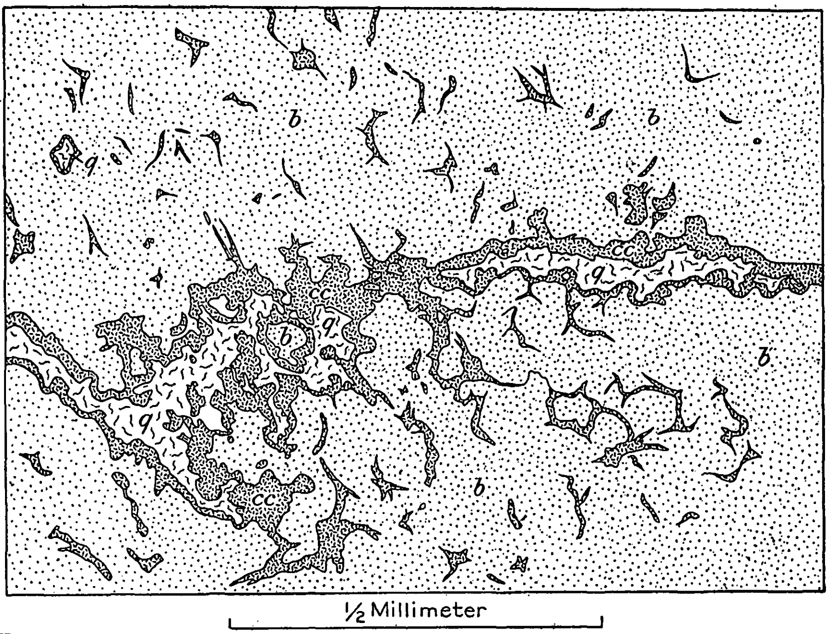

FIGURE 19.—Microdrawing of polished surface of ore from the Queen mine. Outlined with camera lucida. Bornite (*b*) showing infiltration of quartz (*q*) in irregular veinlets (perhaps when sulphide was chalcopyrite), followed by the formation of chalcocite (*cc*) at the expense of the bornite. Illustrates gradation between chalcocite formed along a fissure and chalcocite developing in the bornite without distinct fissuring and in forms suggestive of contemporaneous intergrowth.

visible cracks or openings, but takes place within the apparently solid mass of the older mineral. Graton and Murdoch [1] apparently refer to the same phenomenon when they state that "with bornite it appears that as soon as the solutions reach one portion of a grain the whole area may become unstable and break down, so that instead of finding the usual growing veinlet of the secondary mineral traversing and gradually replacing the one undergoing alteration, we often find in the case of bornite indefinite areas over part or all of which minute particles of the secondary minerals have developed." The

[1] Op. cit., p. 23.

change from bornite to chalcocite, however, can hardly be merely an internal rearrangement, but involves chemical interchange, at least to the extent of removal of the iron present in bornite. The sulphide minerals are probably permeable to solutions through openings too small to be seen by the ordinary microscope; in fact, were this not the case the formation of more than a molecular film of chalcocite on the walls of a fissure in bornite would be impossible, unless we admit that ions carried in solutions in the fissure may be handed on by chemical reaction from one molecule to another into the solid substance of the inclosing mineral. Moreover, in this connection it is well to remember that observations are made on polished opaque surfaces and that exceedingly minute cracks might have their edges burred by the mechanical action of polishing and so become superficially closed and invisible. Such cracks might not be revealed even by the etching which brings cleavage structure to light. Furthermore, such a section may in places be nearly parallel with a crack, so that wide areas of apparent intergrowth may be only a short distance from a crack lying perhaps only a fraction of a millimeter below the surface of the section.

If the origin of the apparent intergrowths in the ore of the Queen mine is correctly inferred, it follows that secondary processes in sulphide ores may produce structures which it is difficult and perhaps in some cases impossible to distinguish from contemporaneous intergrowths.

Covellite was noted in one hand specimen and a very little was seen in the polished sections. It is clearly secondary after pyrite and chalcopyrite, but apparently in this deposit represents an exceptional and transient stage in sulphide alteration.

ORIGIN OF THE QUEEN ORE.

It has been shown that the principal minerals of the Queen ore body were deposited in the following order: (1) Pyrite, (2) chalcopyrite, (3) quartz, (4) bornite, (5) chalcocite, possibly preceded by minor deposition of quartz and accompanied by an insignificant second generation of chalcopyrite.

The visit on which these notes are founded was altogether too brief to throw any particular light on the original source of the ore materials. It may reasonably be assumed on the basis of our general knowledge of ore deposition that some of the earlier minerals were deposited by ascending hot solutions. The term *primary* is commonly applied to such minerals, but the word denotes merely a sequential relation and as used by writers on ore deposits is often vague and may be actually misleading. I prefer to distinguish them as *hypogene* minerals. Similar objection may be made to *secondary* as it is frequently used, often tautologically with *enrichment*. The suggestion is offered that minerals deposited by generally downward-moving and initially cold [1] solutions may be termed *supergene* [2] minerals. It has been shown, for example, that chalcopyrite in the Queen ore is secondary in its relation to pyrite, yet both sulphides are perhaps hypogene. On the other hand, certain deposits of chalcocite in the red beds of the Southwest may be primary in the sense that the chalcocite has not replaced an older sulphide, and yet the deposit may be supergene in origin. As regards the Queen ore, the problem of chief interest and one open to at least a preliminary attack with data now available is to determine which constituents of the ore are hypogene and which are supergene.

Observation of microscopic sections establishes the depositional sequence but can not alone supply the answer to this question. It can not tell us at what point in the sequence the work of ascending waters ended and the work of descending waters began. Light must be gained from the circumstances of occurrence and from chemical considerations.

The field relations at the Queen mine are as yet imperfectly known. All the sulphides are present on the 800-foot level and the downward vertical gradation from rich ore to lean pyritic sulphide, if it occurs, is something that only deeper mining can expose to observation. Nevertheless, chalcocite appears to be the dominant sulphide on the upper levels, under the oxidized zone, and bornite and chalcopyrite form a larger proportion of the ore on the 800-foot level. This alone is suggestive of a supergene origin for the chalcocite, and in connection with what is known of other occurrences of this sulphide, particularly in the same region, such origin may be accepted without much question.

On the other hand, chalcopyrite (exclusive of the insignificant later generation) may on similar general grounds of probability be eliminated from the doubtful zone and assigned to the hypogene group. Its close association with pyrite and the fact that it is older than the quartz gangue point to hydrothermal deposition. Graton and Murdoch,[3] on the basis of wide metallographic observation, have concluded that the structural association of pyrite and chalcopyrite exemplified by the Queen ore is invariably "primary," and R. C. Wells [4] has shown that in "simple precipitative reactions" chalcopyrite is not likely to be deposited from acid solutions, such as are generally

[1] It should be remembered, however, that under certain conditions considerable heat may be generated in the process of sulphide oxidation.

[2] This word is obviously of hybrid construction, but the philologically more correct *epigene* is already too fully occupied in other uses to serve the present need.

[3] Op. cit.

[4] The fractional precipitation of sulphides: Econ. Geology, vol. 5, 1910, p. 13.

active in downward enrichment. With reference to the last statement, however, it must be said that the metasomatic replacement of pyrite by copper sulphide through the agency of sulphate solutions is perhaps not a simple precipitative reaction, at least so far as regards the iron which is already on the ground, ready to combine with copper as chalcopyrite, and that, moreover, under some circumstances supergene chalcopyrite certainly does form. Graton and Murdoch[1] suggest that this mineral when "secondary" probably belongs to the deeper part of the zone of enrichment, where the solutions may be deficient in acid. It is noteworthy, however, that according to the Stokes equation for the formation of chalcocite from pyrite by neutral cuprous sulphate, sulphuric acid is abundantly generated by the actual process of chalcocitization.

There remains to be considered the bornite, concerning which, so far as relates to the question of its hypogene or supergene origin, the available evidence is admittedly inconclusive. If it is hypogene, then its formation was separated from that of the other hypogene sulphides by fissuring, deposition of the quartz gangue, and renewed fissuring. If it is supergene, it was formed directly in advance of the chalcocite by the same sulphate solutions that generated that mineral. Although the bottom of the bornite has not been reached, the ore with abundant bornite grades in some directions into leaner material and clearly represents local concentration in the lode. This concentration is suggestive of supergene origin. The bornite is more abundant in the lower part than in the upper part of the ore body, and this fact gives additional force to the suggestion. Finally, the apparent occurrence of the rich ore in two shoots each related to one of the two zones of juxtaposition of the quartzite with the dike accords best with the view that the bornite was formed by descending solutions. The quartzite, it is to be observed, is the principal water-bearing stratum, and just above it, at the base of the Devonian limestone, occur lenticular layers of copper-bearing sulphides which in their oxidized and leached form will be referred to presently in connection with the Lake Superior & Arizona mine. It is not unlikely that the solutions which found their way along the quartzite carried copper dissolved from some of these lenticular bodies and added their burden of this metal to that carried by waters which moved more directly downward through the dike. If a mingling of solutions, such as is here suggested, was an important factor in the localization of the ore shoots, evidently the vertical range of each ore body must have depended to some extent on the hydrostatic relations of the water in the dike to the water in the quartzite and on the relation of surface

[1] Op. cit., p. 38.

supply to deep drainage. It is entirely possible that, as the mine becomes more extensive, the ore in the two shoots may be found to merge in places across the interval which has been found unproductive in the present workings. As yet too little is known to permit the laying of heavy stress on the supposed distinctness of the two ore shoots seen in 1912. Furthermore, present conditions do not justify the assumption that the formation of chalcocite and other sulphides took place only below water level. It is probable that oxidation and the water level that limits it have advanced downward on the chalcocite zone and that the chalcocite has itself been oxidized in part, dissolved, and reprecipitated. Two essential conditions for important sulphide enrichment appear to be the absence of free oxygen in the zone of deposition and the existence of deep drainage. These conditions may exist above the water level, and the depth to which deposition may extend below that level would seem to depend largely on a deep and slow movement of the underground water sufficient to remove the solution which has lost its copper and to bring fresh supplies of that metal down from above.

On the whole the evidence now available is believed to indicate that the high-grade ore of the Queen mine is the product of downward sulphide enrichment.

OCCURRENCE OF ORE IN THE LAKE SUPERIOR & ARIZONA MINE.

At several horizons within about 20 feet of its base the Devonian limestone has been brecciated along bedding planes, and this brecciation is associated in surface exposures with considerable limonite, manganese oxide, and some quartz and hematite. In places this brecciated material is irregularly veined with malachite and chrysocolla. Near the mouth of the Carlton tunnel this ferruginous layer is about 4 feet thick and about 20 feet above the base of the Devonian. What apparently is the same rusty layer is visible for considerable distances along the mountain side both north and south of Queen Creek. Underground workings, however, show that the brecciation is not everywhere at the same stratigraphic horizon, and some of the brecciated masses are lenticular. Although some bunches of oxidized copper ore have been found in the brecciated layers, most of these have a porous character and appear to have been leached of their copper. Whether this has been carried down the dip and concentrated in workable bodies of ore below the level of the Carlton tunnel is a question that the present workings do not satisfactorily answer. The conditions at the Queen mine indicate that in this district the possibility of enrichment to a considerable depth below the water level should be fully considered.

ORE BODY OF THE SILVER KING MINE.

The Silver King mine was well described by W. P. Blake[1] 30 years ago, but his original publication is not readily accessible. Accordingly, although the present paper is concerned mainly with the copper deposits, and although the old mine, being full of water, could not be reexamined, a brief descriptive summary of the conditions under which the ore occurred will perhaps be of sufficient interest to warrant its inclusion here.

The eruptive mass which incloses the ore is a quartz diorite porphyry or closely related rock. It presents some rather noticeable variations, which Blake distinguished as "porphyry," "sienite," and "granite," although they appear to be merely facies of one intrusive body which is probably of Mesozoic age.

The ore body formerly cropped out at the top of a little hill about 75 feet high, composed of much-altered yellowish-brown to greenish-gray porphyry. Stoping was carried to the surface and a crater-like pit from 100 to 125 feet in diameter marks the site of the former outcrop. Here and there in the porphyry walls of the pit may be found small veinlets of rich, partly oxidized silver ore, but, so far as can be seen from the surface, the ore body was not part of a vein, and there is nothing to suggest that it was determined by the intersection of two or more persistent fissures. It apparently was a compact plexus of veinlets inclosed in comparatively unfissured porphyry.

Blake's description and the maps of underground workings show that the ore body was a stockwork about 130 feet in maximum diameter, with a general dip of 70° W. The stockwork was disposed about an irregular core or axis of milk-white quartz, containing some bunches of rich ore but as a whole comparatively barren. This material is abundant and conspicuous in the mine dump and evidently constituted at times the bulk of the waste. The ore consisted of altered porphyry traversed in all directions by innumerable veinlets carrying stromeyerite, tetrahedrite, galena, sphalerite, chalcopyrite, and pyrite in a gangue of quartz with some barite. The minerals named were noted in 1912 on the dump, but Blake lists and describes also native silver, argentite, bornite, calcite, and siderite. Bornite, chalcopyrite, and pyrite are said to have been comparatively rare. Blake makes the interesting observation that stromeyerite and highly argentiferous tetrahedrite with more or less argentite were the most important constitutents of the ore on the upper levels, whereas argentiferous sphalerite had become the principal ore mineral on the seventh level. Native silver, associated with stromeyerite and sphalerite, was abundant on that level, according to the same

[1] Description of the Silver King mine of Arizona, New Haven, 1883, 48 pp., with illustrations.

observer. He also describes the metallic minerals as occurring generally along the medial plane of the veinlets, a characteristic that is verifiable in specimens collected on the dumps in 1912. Apparently the deposit was not deeply oxidized and veinlets seen in the open pit in 1912 showed sulphides present with cerargyrite, malachite, and azurite. Blake notes also native copper, cuprite, " oxides and carbonates of lead and possibly embolite, the chlorobromide of silver; also the argentite, in pure black lumps."

From the fact that water is now flowing from the collar of the No. 2 shaft the original water level was probably close to the surface. The quantity of water pumped to keep the mine clear near its maximum development in 1887 was 10,941 gallons a day.[1] Blake states that at the time of his visit (1882 or 1883), when the mine was 714 feet deep, only 2,000 gallons a day was pumped, all of which entered the mine at the first or 114-foot level.

In the early stages of development, before there was a railroad in Arizona, some rich ore was shipped under great disadvantages. Blake states that some of this carefully sorted ore averaged $1,000 a ton, and as late as 1887 the superintendent, Mr. Arthur Macy, reported assays up to 447 ounces of silver to the ton in ore consisting chiefly of tetrahedrite. Subsequently two 20-stamp mills were built at Pinal, 5 miles from the mine. Some idea of the character of the ore during a rather late stage in the activity of the mine is obtainable from the company's report for 1887, wherein it is stated that mill No. 1, employing wet crushing and concentration, treated 2,698.75 tons of ore with an average content of 21.08 ounces of silver to the ton. The product was 577,813 tons of first-class concentrates averaging 834,135 ounces of silver to the ton and 31 per cent of lead. Of the total silver contents, 53.95 per cent was native silver. In addition the mill turned out 1,261.55 tons of second-class concentrates carrying 31.77 ounces of silver to the ton, chiefly combined in zinc blende and galena. Mill No. 2, in which chloridizing, roasting, and pan amalgamation were employed, treated 4,840.08 tons of first-class ore, averaging 32.47 ounces of silver to the ton of roasted pulp, 1,913.51 tons of second-class concentrates, and 3,875.34 tons of old tailings with an average content of 12 ounces of silver to the ton. The superintendent states that whereas previously the ore treated in this mill had carried 50 per cent of its silver in native condition, the proportion for the year covered by the report had fallen so notably and the bullion, notwithstanding an extraction of over 96 per cent of the total silver, had become so base that he had stopped this method of treatment and was experimenting with an old lixiviation plant previously used.

[1] Report of the Silver King Mining Co. for 1887, San Francisco, 1888.

Various explanations are given locally for the failure of this interesting deposit below the 800-foot level, some stating that the ore body was faulted, some that the ore changed in character and grade. The latter is probably true. The worked-out part of the deposit appears to have been a striking example of deep downward enrichment. If so, the time may come when the old mine will be reopened and its low-grade hypogene ore utilized.

COPPER DEPOSITS OF THE WHITE MESA DISTRICT, ARIZONA.

By James M. Hill.

GENERAL FEATURES OF THE DISTRICT.

Location.—The White Mesa mining district, sometimes called the Keams district, is in the Navajo Indian Reservation, Arizona, 100.2 miles N. 9° E. of Flagstaff and 34.8 miles N. 10° W. of Tuba City, as measured on the Land Office map of Arizona issued in 1909. It lies in unsurveyed territory but is approximately in T. 37 N., Rs. 9 and 10 E., Gila and Salt River meridian. It covers an area about 5 miles east and west by 3 miles north and south, though some claims not visited by the writer are located about 3 miles west-northwest of the main group.

Roads and transportation.—To reach the district the main Lees Ferry road is followed north from Flagstaff to a tank about 10 miles north of Willow Springs and 18 miles northwest of Tuba City, at the base of Echo Cliffs. From this point a rough road ascends the cliffs and reaches the surface of the lower mesa through a gap in the ridge at its western edge. The road then turns almost due north. The distance from Flagstaff to the claims by road is between 135 and 140 miles and is increased a few miles if a detour is made to Tuba City. For at least two-thirds of the distance the roads are fair, but in the remaining third it is necessary to go through deep sand that makes heavy freighting well-nigh impossible. The trip from Flagstaff to the claims by team occupies from 6 to 10 days, and the cost of freighting small lots is probably about 3 cents a pound, or $60 a ton. It is possible for an automobile to go from Flagstaff as far as the tank at the base of Echo Cliffs, about 18 miles from the deposits, in less than a day.

Topography.—The district is on a low divide that runs east and west for a number of miles across the relatively level plateau extending from Echo Cliffs to the Colorado River canyon at an elevation of approximately 6,250 feet. Between the cliffs and the main claims of the district the level of the plateau, which in this paper is called the lower mesa, is broken by small hills and shallow drainage lines marked by low cliffs. Five miles south of the district there is a bowl-shaped depression about 75 feet below the general level.

The east-west divide has an average elevation of 6,400 feet, though at least two points attain a height of 6,500 feet. These two peaks are marked by United States land monuments 1 and 2 and are about in accord with the highest mesa at the extreme east end of the mineralized area.

The middle mesa, 6,400 feet in altitude, is much dissected, as a consequence of which it is irregular in detail and marked by numerous high and low cliffs and by benches at various elevations.

General geology.—The Lees Ferry road at the base of Echo Cliffs passes over red, purple, and bluish-green shales and thin-bedded impure limestones and is probably near the top of this series, for as soon as the ascent of the cliffs is begun massive dark-red sandstone appears which continues nearly to the base of the hills on either side of the gap through which the road passes upon the lower mesa. This sandstone is 400 to 500 feet thick and is composed of rather massive members which exhibit some cross-bedding. The red sandstone forms the floor of the south end of the lower mesa.

Above this red sandstone lie strongly cross-bedded, light-colored, very friable sandstones, that stand up as low hills and cliffs at least 270 feet high. The hills are the remnants of the lower part of a series that is exposed at the summit of Echo Cliffs, where it shows at least 350 feet of white, buff, and light-red sandstones without fossils, and is everywhere marked by intricate cross-bedding. In these sandstones the sand grains, though fine, are distinct. They are set in a white, pink, or buff-colored matrix which weathers very rapidly, leaving the heavy sand that covers so much of the area. The matrix is essentially clay, in which there is some very finely comminuted quartz. To recapitulate, the stratigraphic series of the mesa, beginning from the top, is about as follows:

White to buff friable sandstones, very strongly cross-bedded, forming the higher hills on which the copper claims are located. This is probably to be correlated with the lower portion of the La Plata sandstone (Jurassic) of southwestern Colorado and southeastern Utah.

Red sandstones, rather massive, with thin conglomerate lenses near central and upper portions. Forms lower part of Echo Cliffs. Probably to be correlated with the Dolores formation (Triassic) of southwestern Colorado and southeastern Utah.

Green, purple, and red shales, thin bedded and containing some beds of conglomeratic limestones, exposed under Echo Cliffs along the Lees Ferry road. Permian (?).

Structure.—On White Mesa the light-colored sandstones lie flat, apparently being undisturbed by either tilting or faulting. They are so strongly cross-bedded that local observations for dip and strike give widely varying results, though the true bedding is essentially horizontal. The only openings are joint planes, some of which seem to have had an influence on the deposition of the ores.

At Echo Cliffs the massive red sandstone and underlying shales have an apparent dip of about 20° ENE. This dip appears to be localized along the cliffs, for near the rim of the lower mesa the red and white sandstones are practically flat.

ORE DEPOSITS.

The copper ores found in this region are chrysocolla and malachite, locally, with a very minor quantity of azurite. Chrysocolla is by far the most widely distributed copper mineral, occurring as a greenish-blue cement to the sandstone. Malachite, the next in abundance, is in places associated with very dark brown hematite and forms small irregular masses in the chrysocolla ore. In a very few places it occurs alone. These two minerals may be said to constitute the ore, as the azurite is very scarce. The specific gravity of the ore is about 2.61, and a ton of it occupies about 12⅓ cubic feet.

The ores occur in the lower middle portion of the white cross-bedded sandstone as rather small, very irregular bodies of blue color, distinct from the barren rock into which they grade. In a few places there are veinlike forms having lateral and vertical dimensions longer than their width, but even in these the margins are not sharply defined, there being a gradation between ore and rock. In some places the ore occurs on either side of small open crevices that appear more like joint planes than fissures, but the largest number of ore bodies occur as small bunches in the sandstone in which there are no apparent openings.

On close inspection the greenish-blue color is seen to be due to the color of the matrix of the sandstone; in other words, the ore minerals have replaced the original cementing material of the sandstone—an impure clay probably containing a large amount of kaolinite. The quartz grains themselves have not been attacked, though in one slide of the ore some of the grains are seen to be cracked, and chrysocolla has been deposited in the openings.

Where hematite occurs it replaces the matrix of the sandstone in the same manner as the copper silicate.

The ore bodies occur through a vertical range of 250 feet. The lowest deposits noted are on the Nestor claim, at an elevation of about 6,250 feet, and the highest on the Butte Valley claim, on the rim of the upper mesa at an elevation of 6,500 feet.

ECONOMIC CONDITIONS.

Water.—On the road from Flagstaff to the prospects water has to be carried by the freight teams, as there are only five places where it can be obtained, as follows:

1. At the Halfway House there is a natural tank in the bottom of the canyon, about 600 feet east of the road.
2. An artificial tank 1½ miles southwest of the new bridge over the Little Colorado contains water most of the year.
3. Willow Springs.
4. At the point where the road to the claims leaves the Lees Ferry road there is a cement tank about a small seep.
5. Five miles south of the claims and about 1 mile west of the road there are two wells which give a small but continuous supply of water.

No water has been found nearer to the deposits than the two wells last mentioned. Because of the extreme porosity of the sandstone it will be impossible to develop water tanks in the district unless they are entirely lined with cement, which would make the cost almost prohibitive.

It might be possible to obtain water by deep wells, though a 212-foot shaft has encountered none. Probably to reach water the wells would have to go down to the underlying limestone, a distance of 700 to 800 feet.

Development.—Nothing in the way of real mining has been done in the district. There are prospect holes in many places, usually in groups of four to eight pits in a small area around the most promising exposure of ore on each of the claims. These pits are usually 4 by 6 feet in cross section and average from 2½ to 10 feet in depth. Open cuts are numerous in the faces of low benches showing ore, and there are a number of trenches from 2 to 6 feet deep where that method of prospecting was most available. There are some short tunnels, but in only one of these was any considerable amount of ore uncovered. Several shallow shafts have also been put down in ore; the deepest of them is about 30 feet.

Work of this kind, while it discloses the ore on and near the surface, does nothing to determine whether there is any at greater depth.

Quantity of ore.—It is very difficult to make any fair estimate of the amount of ore in these deposits, because of their extreme irregularity and the impossibility of telling in advance of actual development work where ore will be encountered or where an ore body will give out.

The size of the ore bodies exposed by the present development is extremely diverse, ranging from 1 cubic foot up to 10,000 cubic feet, but most of the bodies so far demonstrated contain from 100 to 200 cubic feet of ore.

Value of the ore.—The value of the ore bodies is extremely variable, depending on the degree of replacement. Some bodies are of a very faint bluish-green color, and samples taken from them carry from 0.5 to 3 per cent of copper. The larger part of the ore shown by the cuts is a rather deep greenish-blue material which assays between 5 and 8 per cent of copper. Ore of this class contains small amounts of dark-green malachite-bearing material, with some hematite which is of higher grade. A sample of this ore from the Pais-Lee-Chee claim assayed 14 per cent of copper, and it is possible that by picking even higher assays might be obtained.

Other considerations.—Mining costs would be rather low if it were not for the high cost of supplies. The ore can hardly be smelted, on account of its extremely siliceous character. Certainly it can not be smelted on the ground, because of the lack of flux. It is probably more amenable to leaching. Any leaching process, however, requires abundant water, which has not yet been developed on the ground and which would in all probability be very expensive to obtain. Under present conditions these ores can not be profitably worked, but it is possible that with better transportation a small quantity of copper could be won from the deposits.

SURVEY PUBLICATIONS ON COPPER.

The following list includes the principal publications on copper by the United States Geological Survey or by members of its staff. In addition to the publications cited below, certain of the folios of the Geologic Atlas of the United States contain discussions of copper resources. This list does not include publications on Alaska, a list of which is given in Bulletin 542, the annual report on progress of the Survey's investigations in Alaska for 1912.

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 publications 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.

ECONOMIC GEOLOGY OF THE REGION AROUND MULLAN, IDAHO, AND SALTESE, MONTANA.

By F. C. Calkins and E. L. Jones, Jr.

INTRODUCTION.

The field work of the authors in 1912 was devoted chiefly to the geologic mapping of the northern part of the quadrangle bounded by parallels 47° and 47° 30′ N. and meridians 115° 30′ and 116° W. and embracing parts of northern Idaho and northwestern Montana. This unit in the regular quadrangle system overlaps the southeastern part of the Cœur d'Alene quadrangle, whose general and economic geology was studied about eight years ago and described in a Survey publication;[1] and a welcome opportunity was thus afforded to gain information concerning recent developments in a part of the Cœur d'Alene mining district. About a month was accordingly devoted to this revisory work, which consisted mainly in the study of mines and prospects near Mullan, Idaho, but included a cursory visit to several prospects near Wallace and some review of the areal geology.

The season's work also comprised the examination of many prospects in an area surrounding Saltese, Mont., which has long been the scene of mining exploration but in which no steadily productive mine has yet been developed. Virtually nothing has been published concerning this area, although two brief papers give some account of the region to the south and southwest of it.[2] The location of the area discussed in this paper is shown in figure 20.

The present paper is intended to give a brief account of the economic information thus gathered, with so much of the geography and geology as seems pertinent to the main object. Any usefulness that it may have should be credited in large measure to the aid and facilities offered by the mining men of the region. Among those to whom special acknowledgment is due are the officers of the Morning, Snowstorm, and Gold Hunter mines. Mr. George Huston, of Mullan,

[1] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.

[2] Pardee, J. T., Geology and mineralization of the upper St. Joe Basin, Idaho: Bull. U. S. Geol. Survey No. 470, 1911, pp. 39–61. Calkins, F. C., and Jones, E. L., jr., Geology of the St. Joe-Clearwater region, Idaho: Bull. U. S. Geol. Survey No. 530, 1913, pp. 75–86.

generously gave many hours to our guidance and has kept us informed by letter on developments that have occurred since we left the field.

Many prospects in the area represented by the geologic map (Pl. III) were not visited, and the reader should not infer that any prospect not described is necessarily unimportant. It is believed, however, that the properties visited illustrate the main features of the ore deposits.

GEOGRAPHY.

TOPOGRAPHY.

Mullan and Saltese lie in the heart of that broad zone of mountainous topography which forms the western part of the Rocky

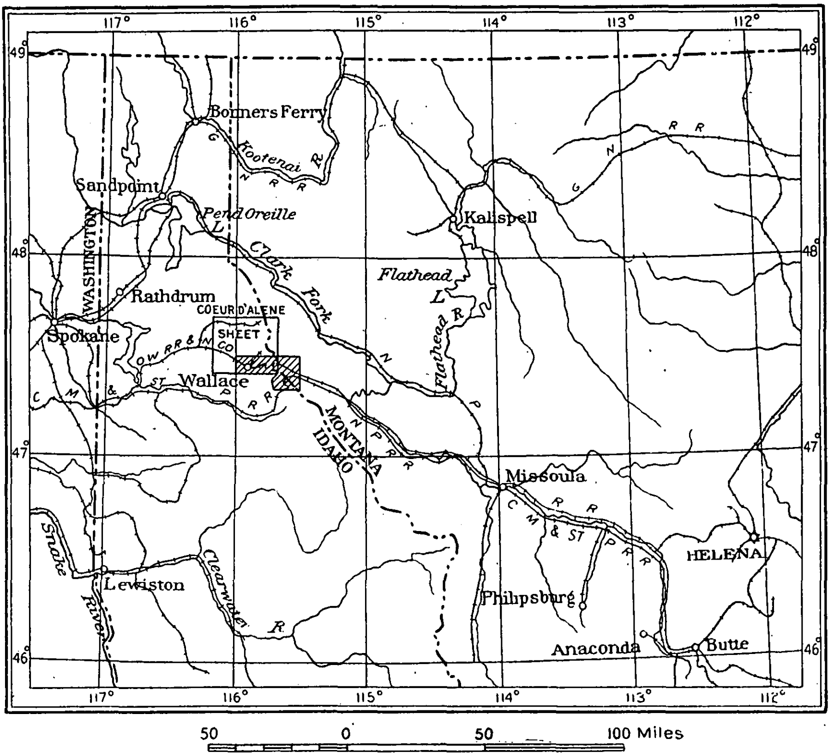


FIGURE 20.—Index map showing (by shading) location of region around Mullan, Idaho, and Saltese, Mont.

Mountain system north of the Snake River Plains. In the vicinity of these towns few of the summits exceed 6,500 feet in height, and the panorama from any commanding viewpoint suggests a surface of low relief that has been elevated and throughly dissected by streams. The valleys of this general region are relatively narrow and intricately branched. The smaller ones have no characteristic trend, but most of the larger ones have a general course near east-west or southeast-northwest, and this rule is strikingly exemplified in the area here discussed.

This area is crossed from east to west by a depression of more than local interest, which follows, with comparatively slight deviations, a straight line extending east-southeastward from Spokane, Wash., to Deer Lodge, Mont., a distance of 300 miles. Clark Fork of Columbia River flows westward in this depression from Deer Lodge to St. Regis, Mont., where it turns abruptly eastward and makes its way through a narrow gorge to another long transmontane valley. The western part of the depression is occupied by Spokane River and the Cœur d'Alene and its South Fork. The section between Clark Fork and the head of the Cœur d'Alene might appear, from inspection of a small-scale map, to be occupied by St. Regis River. In reality, however, the connecting link between the valleys of these two major streams is a trough that parallels the St. Regis Valley a short distance to the north, extending from St. Regis to the broad and deep saddle at the head of the Cœur d'Alene. This trough will be referred to in the following pages as "the old valley," for this term suggests its evident origin. Its general form is that of a mature stream valley, such as must have been excavated by a river comparable in size and age with the South Fork of the Cœur d'Alene. The work of such a stream is further attested by deposits of well-rounded gravel, containing bowlders whose source was evidently west of the present State boundary and covering remnants of the ancient valley floor. The valley has been abandoned, however, by the stream which carved it and is now drained by several tributaries of St. Regis River. The course of these tributaries is in general transverse to that of the old valley. The largest is Packer Creek, which enters the St. Regis at Saltese and whose relation to the depression is typical. The main trunk of Packer Creek is only a mile long and flows in a narrow canyon through a range of rather high hills; this trunk has three main branches, one of which flows due south from the mountains to the north, one westward about parallel to the axis of the trough but somewhat south of it, and another at first east along the axis and then southeast against the south slope. Farther west Randolph and Brimstone creeks likewise make their exit from the valley by way of transverse canyons. The erosion of these streams and their many tributaries has entrenched the floor of the old valley to a depth amounting in some places to several hundred feet, and one effect of this erosion has been to form, along the middle of the valley, a little range of rounded hills, the most conspicuous of which is Meadow Mountain, between the North and East forks of Packer Creek.

Considered in its entirety, this 300-mile depression has some of the characteristics of the physiographic type which Daly[1] calls a

[1] Daly, R. A., The nomenclature of the North American Cordillera: Geog. Jour., vol. 27, 1906, p. 596.

trench. According to Daly's definition, a trench is a "long, narrow intermontane depression, occupied by two or more streams * * * alternately draining the depression in opposite directions." The application of some such term as "Cœur d'Alene trench" to the feature under discussion might be desirable on the ground of convenience and because it would serve to emphasize the importance of this depression, but it is not formally proposed, for the term "trench" connotes a regularity of cross section that is not present here.

The geographic importance of this long depression cutting across a large part of the Rocky Mountains has long been practically recognized by its utilization as a route of travel. Most of it is now occupied by railways. These were preceded by the old Mullan Road, and this, in turn, by more or less definite Indian trails. The graded floor of St. Regis Valley, however, has generally been used in preference to the dissected floor of the old valley farther north.

The geologic history of this depression is very imperfectly known. It is clearly of considerable age, for it coincides in part with remnants of valleys that can not be later than Tertiary. Its location has been determined in large measure by faulting, this being demonstrably true of the part with which this paper especially deals.

TIMBER.

The entire region was once covered with a heavy stand of timber, much of which was of excellent quality, but only a very small proportion of this growth remains alive. Much has been cut by lumbermen and miners and a great deal more has been destroyed by repeated fires, so that no considerable areas of virgin forest are now standing except in the extreme eastern part of the area and near the Bitterroot divide, north of St. Paul Pass. Great numbers of fine trees, especially in Montana, killed by the fires of 1910 are still usable, however, and have been sold to lumber companies, who are working on a large scale to remove and utilize them. The fires have depressed the general prosperity of the part of the area lying in Montana and have perhaps been the cause of the failure to produce ore from some properties, for they not only increased the difficulty of obtaining mine timbers but destroyed buildings of considerable value.

SETTLEMENTS AND ROUTES.

The three important settlements of the region here considered are Wallace, Mullan, and Saltese. Wallace, which has a population of about 3,000, is the seat of Shoshone County and the metropolis of the Cœur d'Alene mining district. Mullan, another flourishing mining center, has a population of about 1,700. Saltese, with about 350 inhabitants, is a supply point for prospectors. Taft, a few miles farther west, is a still smaller hamlet.

The main line of the Chicago, Milwaukee & Puget Sound Railway crosses the area, closely paralleled east of Taft by the Cœur d'Alene branch of the Northern Pacific Railway, whose terminus is at Wallace. Wallace is connected with Spokane by the Oregon-Washington Railroad & Navigation Co.'s line. Roads and trails are fairly numerous. An automobile road, that has been completed recently, follows the old valley for several miles. The Bitterroot divide is followed by a good trail and is accessible by a carefully graded road between the Monitor mine and Saltese.

GEOLOGY.

PRINCIPAL FEATURES.

The dominant rocks of the area (Pl. III) belong to the Belt series, of Algonkian age, which has a great development in northern Idaho and northwestern Montana. This series consists of many thousand feet of fine-grained sedimentary rocks, including quartzites of varying purity, shales, and impure limestones, which appear to have been deposited, for the most part, in shallow water. Old as they are, these rocks have, on the whole, undergone but little metamorphism. They are very extensively and thoroughly metamorphosed in the basin of Clearwater River,[1] but about Saltese they show their usual lack of conspicuous alteration. The formations represented here comprise all those described in the early report on the Cœur d'Alene district except the lowest. They have the same general characteristics here as in the Cœur d'Alene district, but show some noteworthy variations even within the limits of the area here described.

Igneous rocks are scarce within this area. The most abundant is diabase, the largest mass of which forms a great sill in the Algonkian sedimentary rocks. There are also some small dikes, chiefly of lamprophyric character. Light-colored granular intrusive rocks, such as occur a short distance northwest of Mullan and in the Clearwater basin to the south, are absent.

The structure is moderately complex on the whole, but differs in complexity from place to place. Its most significant feature is a fault zone coinciding with the trench.

A great part of geologic time is in this area unrepresented by sedimentary deposits, of which there are none intermediate in age between the Algonkian sedimentary rocks and some presumably Tertiary gravels that form small patches on the floor of the trench and were evidently laid down by the fairly large stream that once occupied it. These gravels are not of economic importance except in the negative sense that they conceal the rocks beneath, which may be metalliferous, and they will therefore receive no more than this passing mention. The more recent stream gravels, on low terraces and

[1] Calkins, F. C., and Jones, E. L., jr., op. cit.

flood plains, and the extinct alpine glaciers, which have carved cirques on the north and east sides of the main divides and left some rather inconspicuous moraines, may similarly be dismissed. More detailed description must be accorded to the older rocks and the structure by reason of their intimate relation to the ore deposits.

ALGONKIAN SEDIMENTARY ROCKS.

BELT SERIES.

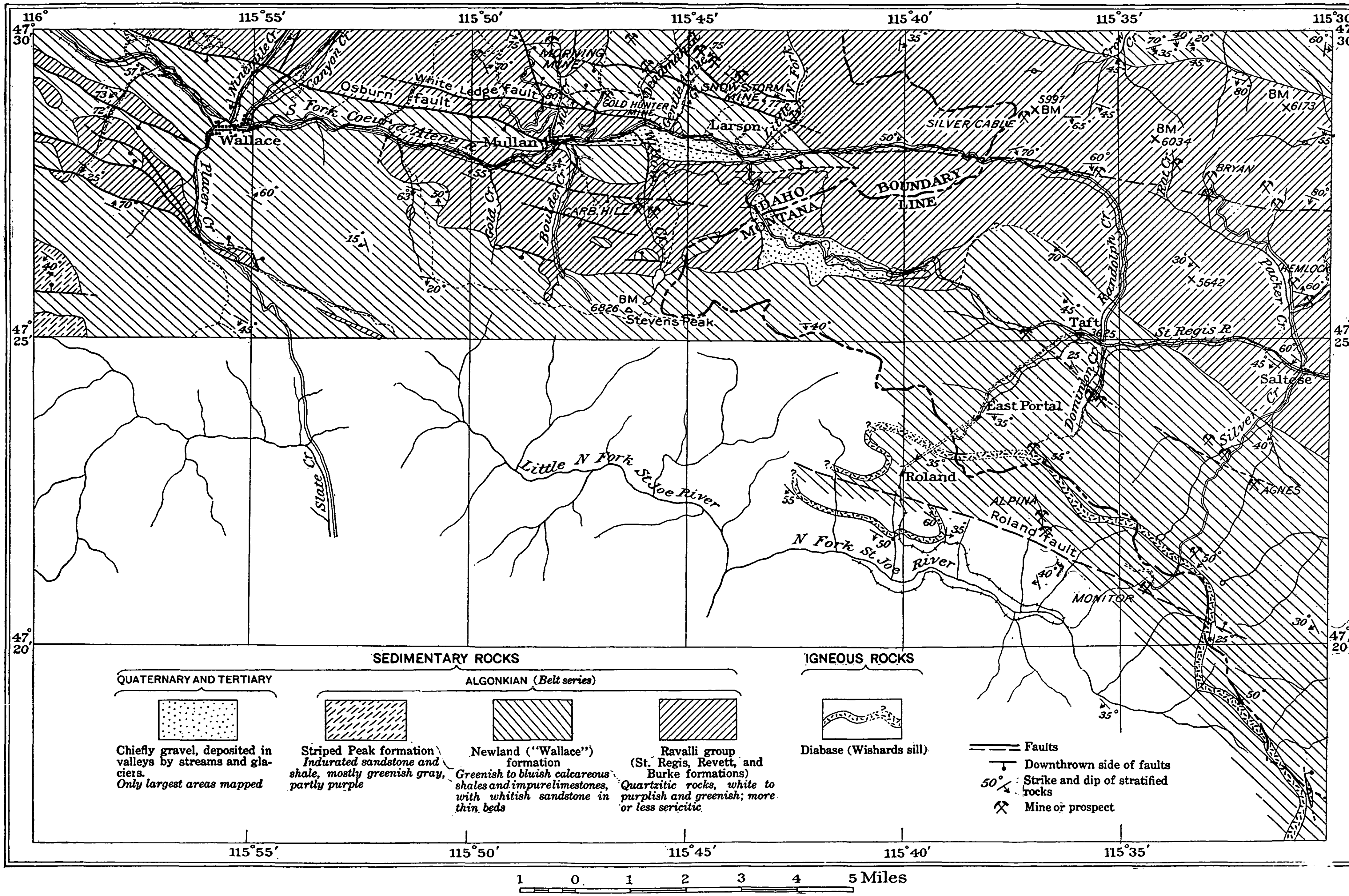
RAVALLI GROUP.

The three lowest formations of the Belt series in this area compose the Ravalli group. Named in ascending order they are the Burke formation, the Revett quartzite, and the St. Regis formation. The Ravalli group is overlain by the Newland ("Wallace") formation. In other areas it is underlain by the Prichard formation, which is not present in the areas discussed in this paper.

Burke formation.—The Burke formation, the lowest formation of the Ravalli group, consists in general of fine-grained, light-colored thin-bedded siliceous rocks. Its most abundant and characteristic rock is a light greenish-gray flaggy impure quartzite or siliceous shale, which derives its tint and a certain degree of softness from the presence of sericite, a white mica in a state of fine division. The lowest beds exposed in the area include some material with a darker bluish tint, and the upper part contains quartzite which is rather thick bedded and contains but a moderate amount of sericite; this makes it difficult to draw a sharp line between the Burke formation and the overlying Revett quartzite. The thickness of the Burke was estimated in the early study at 2,000 feet, and the present review has given no basis for a correction of this estimate. This formation occupies a large area north of the trench and northwest of Mullan.

Revett quartzite.—The Revett quartzite, the middle formation of the Ravalli group, is somewhat similar to the underlying Burke formation, but consists of thicker-bedded and more purely siliceous rocks. The lower middle part comprises some hard and brittle, almost glassy quartzite. The upper part, however, is perceptibly sericitic and greenish and therefore similar in a measure to parts of the underlying Burke formation and the overlying St. Regis formation, though thicker bedded than the Burke and lacking the distinctive coloration of the St. Regis. The formation is about 1,200 feet thick.

St. Regis formation.—The St. Regis formation, the upper formation of the Ravalli group, as developed in the Cœur d'Alene district, is composed of indurated shales and quartzitic sandstones characterized by shallow-water markings and by comparatively pronounced tints of green and purple. Neither of these hues predominates distinctly over the other, but the purple tint is the more characteristic. In



GEOLOGIC MAP OF REGION AROUND MULLAN, IDAHO, AND SALTESE, MONT.

some beds it is pale and dull and perceived with some difficulty by observers not accustomed to look for it; in others it is rich and dark, though not brilliant. These tints are typically displayed in the vicinity of Mullan, where the uppermost beds of the St. Regis are dark bluish-purple slates in sharp contrast with the green slates of the lower part of the Newland ("Wallace") formation. The dull-lavender quartzitic sandstones in the lower part of the St. Regis are less distinct from the greenish-gray rocks of the upper part of the Revett.

This distinctive coloration of the St. Regis formation is much less marked farther east. The uppermost beds of the formation are certainly paler near Borax, on the St. Regis, than they are on Mill Creek, and near Saltese the purple tint of these beds is so faint that there is real difficulty in fixing a boundary between them and the slates of the Newland formation. The coloration of the lower beds is still more indefinite; they are in general greenish and thicker bedded than the upper beds and therefore approach the upper Revett rocks in character. The railway section between Saltese and Deborgia and still farther east exposes so great a thickness of these dull-greenish impure quartzites as to give the impression that any distinction here between the St. Regis and the Revett would probably be impossible. To the north of the old valley, however, the Revett quartzite and the Burke formation are extensively exposed, each with a lithologic character that is typical and fairly distinct from that of the St. Regis. The thickness of the St. Regis near the northeast corner of the area described is about 1,000 feet. Its thickness farther south is apparently greater, but is difficult to measure owing to the indefiniteness of the lower limit.

NEWLAND ("WALLACE") FORMATION.

The Newland is the thickest formation in this area and occupies the greatest portion of its surface, being the principal country rock south of Cœur d'Alene and St. Regis rivers.

In the original reports on the Cœur d'Alene district it was mapped and described as the Wallace formation, but it has since been correlated with the Newland formation to the east, and the local name (Wallace formation) is no longer used.

The formation as a whole consists of thin-bedded rocks which are for the most part calcareous. The rocks contain carbonates of magnesium and iron as well as of calcium, but the calcium seems the most abundant. The formation comprises three members which are fairly distinct in general character, but which grade into one another and are not distinguished on the map.

The lowest member is characterized by the prevailingly green color of its rocks. The strata immediately above the St. Regis consist of obscurely banded slates, of a rather bright apple-green color, which are very slightly calcareous, their separation from the St. Regis being determined rather by convenience than by strict logic. Higher in the formation the proportion of limy material is greater, as is indicated by the yellow color assumed by the rocks when weathered; numerous bands of whitish calcareous sandstone and a few strata of blue and white argillite make their appearance. The part of the formation in which the green color is strongly preponderant constitutes what may conveniently be called the lower member.

The middle member contains greenish beds but is characterized more especially by blue and white banded argillite and an abundance of calcareous sandstone or quartzite, together with some impure limestone. In its upper portion the limy and sandy layers diminish in quantity, and finally it passes into a blue, regularly banded noncalcareous shale. This in turn is overlain by a comparatively small thickness of green rocks very similar to those at the base of the formation.

The blue shale forming the major part of the upper member presents remarkable variations in thickness. In the basin of St. Joe River, to the south of the area here described, it is apparently not less than 5,000 feet thick, but near Striped Peak, southwest of Wallace, its thickness is insignificant. The thinning of these beds has not been continuously traced and its cause is still obscure.

The lower member of the formation also is of very uneven thickness, being apparently much thicker near Saltese than near Mullan, although the structure is not understood with sufficient thoroughness to permit reliable stratigraphic measurements. The total thickness of the Newland formation in the middle part of the Cœur d'Alene district, where the upper member is almost unrepresented, was estimated as 4,000 feet, but this is certainly less than the combined thickness of the lower and middle members near Saltese.

STRIPED PEAK FORMATION.

The Striped Peak formation occupies only a small part of the area mapped. It consists of shales and sandstones with shallow-water markings, and is remarkably similar to the St. Regis formation. The prevailing color is greenish gray, but some beds are purple.

IGNEOUS ROCKS.

Diabase.—The largest mass of diabase in the region is the Wishards sill, a sheet 400 or 500 feet in maximum thickness, which is intercalated in the middle member of the Newland formation. It persists at the same stratigraphic horizon for a remarkable distance, having been traced from the head of Placer Creek southeastward to St. Joe River, 30 miles away. The constancy of its stratigraphic position proves that it was intruded before the Algonkian rocks were deformed, and it has been folded and faulted with them. It is of great use in deciphering structure, because it is more readily followed than any stratum of the sedimentary series, being generally conspicuous for its dark tone, bold outcrops, and the scantiness of the vegetation growing on it.

The rock has the normal appearance of diabase. Its general color is black to dark gray with a tinge of green; its texture is coarse to fine. The minerals visible to the naked eye are white feldspar, dull greenish-black augite and amphibole, and black iron ore of metallic luster. The feldspar forms crystals that give many narrow oblong sections. No olivine is visible, even under the microscope, which reveals considerable amounts of quartz, alkali feldspar, and biotite.

The shaly rocks of the Newland formation are distinctly metamorphosed by this largest diabase intrusion, but the metamorphism is limited to a distance of a few yards across the bedding.

This diabase also forms some thinner, inconspicuous sills in the Newland formation, one of which, near the boundary between the middle and lower divisions, was seen in several places south of Saltese. Diabase dikes have not been found in the area more especially considered here, although there is one on the south side of Ward Peak, penetrating rocks that underlie the Newland formation.

Other intrusives.—No other igneous rocks than the diabase form large or conspicuous masses, and none are shown on the geologic map.

In the vicinity of Mullan there are numerous dikes of rocks that were classified in the report on the Cœur d'Alene district as lamprophyres. Superficially these resemble the fine-grained portion of the diabase in being dark and of crystalline texture, but they are distinguished from diabase by the presence in them of abundant small needle-like crystals of black hornblende, and their feldspar does not show well-defined outlines. Biotite is somewhat conspicuous in most specimens.

Several of these dikes are crossed by the Hunter tunnel. One or two others crop out in the vicinity of the Gettysburg prospect, and one is cut by the workings of the Morning mine. One or two are penetrated by the workings of the Star prospect, west of the Morning. In this same prospect are two or three dikes of a greenish-gray porphyry, which are possibly offshoots from the monzonite intrusion exposed near Gem, about 2 miles to the northwest, but the rocks are too badly decomposed to supply conclusive petrographic evidence of such a relation.

A thin sill of decomposed basic igneous rock resembling diabase is intercalated in the St. Regis formation on Willow Creek and penetrated by the Carny Copper prospect.

STRUCTURE.

The most remarkable tectonic feature of the region is the fault or fault zone that has determined the location of the long depression of which the valley of the South Fork of Cœur d'Alene River and the old valley are parts. It was found in working out the areal geology of the Cœur d'Alene district that the South Fork approximately coincides with the great Osburn fault, which was traced continuously from Mullan to Wardner and which apparently persists for many miles farther west. At Mullan the fault disappears beneath the alluvial floor of the valley, which is so broad for some distance eastward as to baffle any effort to trace the fault directly, and the upper part of the valley, which is narrower, has not been fully examined for evidence of the continuation of the fault to the east. The old valley, however, is clearly located on a fault or fault zone whose identity with the Osburn fault, though it can not be absolutely proved, is strongly indicated by its direction and position and the fact that, like the Osburn fault, it effects a downthrow on the south. Between Wallace and Mullan the rocks on the south side of the Osburn fault belong chiefly to the Newland formation, while those on the north side are quartzite of the Burke formation and Revett quartzite. The areal relations along the old valley indicate a throw of the same order of magnitude; the rocks on the south belong to the St. Regis formation, and those on the north are ascribed to the Burke and Revett. This is the main evidence of the fault, but it is corroborated by abundant evidence that the old valley coincides with a zone of fracture. Breccias abound on the slope to the north, and every prospect exhibits a remarkable amount of shattering in the country rocks. The poor exposures in the deeply decayed rocks on the floor of the trench make it difficult to follow the line of the fault precisely, but the main fracture is apparently north of Meadow Mountain and the knobs aligned with it.

The course of this great fracture, which may, without serious risk of error, be called, as a whole, the Osburn fault, is a convenient line of reference in characterizing briefly the other structural features of the region, which are by no means thoroughly worked out.

The structure is simpler south of the Osburn fault than north of it. The largest structural feature of the southern area is an anticline, well shown by the map southwest of Mullan. This fold becomes indistinct to the east, but there is some plication along the general line of its axis as far as the longitude of Saltese. The area between the Bitterroot divide and St. Regis River is occupied chiefly by the southwest flank of this anticline, and here southwesterly dips are remarkably persistent. Farther south there is rather complex folding, some of which is clearly expressed by the sinuous trace of the Wishards sill.

In the area mapped south of the Osburn fault few conspicuous faults have been found except at the extreme west, and the only important fault newly mapped in 1912 is that designated the Roland fault. This causes a large displacement of the folded Wishards sill near Roland and is probably the same fault that displaces the sill about 200 feet on the divide. Brecciation, saddles in the spurs, and sharp discordances of dip in the strata mark the line connecting the points at which the fault cuts the sill. The Roland fault might have failed of detection, however, had it not been for its clear effect on the diabase intrusion, and there are indications of other faults which may be considerable, although the evidence of them is not very tangible. A few of the more distinct lines of fracture lying in the Newland formation are shown on the map. An indication of faulting, which there was no opportunity to trace farther, is afforded by the strong jog in the St. Regis-Newland boundary northwest of Taft.

The structure north of the Osburn fault is characterized near and west of Mullan by very complex faulting, which is not fully represented on the map. The fractures range in strike from east-west to north-south. No folds can be traced here for any considerable distance. The structure along the old valley is of the same general character, but the slight variations in the prevailing quartzitic country rocks and the poor exposures make it very difficult to work out structural details. The quartzitic zone is flanked on the north by an area of the Newland formation, in which there is an eastward-pitching syncline.

ORE DEPOSITS.

GENERAL FEATURES AND GROUPING.

The ore deposits of the northern part of the zone described in this report are chiefly valuable for lead and silver, and the potential value of the prospects in the southern part depends mainly on their copper content. No sharp division can be made, however, between a silver-lead belt and a copper belt, for copper deposits, typified by that of the Snowstorm mine, northeast of Mullan, occur in the northern part of the area, and there are at least two lead prospects in the southern copper belt. The prevailing form of the deposits is that of fissure veins, mostly trending east-west to northwest-southeast; but in this respect again the copper deposits of the Snowstorm type are exceptional, for their minerals are finely disseminated in the country rock. The prevailing gangue mineral throughout the region is siderite, the Snowstorm deposits once more furnishing the most conspicuous exception to the rule. In view of these diversities and others, it is convenient to recognize the following more or less distinct subdivisions of the region:

1. The area of silver, lead, and zinc deposits north of the river near Mullan—the Mullan area.
2. The area of silver, lead, and zinc deposits along the old valley in Montana—the Packer Creek area.
3. The area of sideritic copper veins south of Cœur d'Alene River and the old valley—the southern copper area.
4. A zone south and southeast of Mullan transitional in character between 1 and 3—the Willow Creek area.
5. The zone of disseminated copper north of the South Fork of Cœur d'Alene River—the Snowstorm copper area.

MULLAN AREA.

GENERAL FEATURES.

The deposits studied north of the river near Mullan are fissure veins whose walls are more or less indefinite owing to metasomatic replacement. Their chief valuable mineral is galena, but some of the deposits contain a large amount of sphalerite. Silver is an important source of profit and is apparently derived from argentiferous galena and tetrahedrite. The gangue is mainly siderite, but quartz is also abundant and in some properties is the predominating gangue mineral. Copper minerals other than tetrahedrite are of merely sporadic occurrence.

The most productive property in this area is the Morning mine. Second in importance is the Gold Hunter, a comparatively small but steadily productive and apparently profitable mine. The Alice mine, west of Mullan, has shipped ore but has not yet entered the class of steady producers. The remaining properties in the area are prospects of varying degrees of promise.

MORNING MINE.

DEVELOPMENT.

The Morning mine, whose mill and adit are on the South Fork of Cœur d'Alene River, about half a mile below Mullan, is the largest property of the Federal Mining & Smelting Co. and is second only to the Bunker Hill & Sullivan among the mines of the Cœur d'Alene district as a producer of lead and silver. Since 1904, when it was visited by Ransome,[1] it has been much developed and has added zinc to its products. About 1,200 tons of ore a day is now being taken from the mine.

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[1] Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 164.

Information supplied by the company concerning the production of the mine for the years subsequent to 1906 is given in the following table:

Production of the Morning mine, 1906 to 1912, inclusive.

	Concentrating ore.	Shipping ore.	Total.	Ratio of concentration.	Silver.	Lead.	Zinc.
	Tons.	*Tons.*	*Tons.*	*Per ct.*	*Ounces.*	*Pounds.*	*Pounds.*
10 months ending Aug. 31, 1906	248,617	14	248,631	8.8	415,976	25,812,200	....
12 months ending Aug. 31, 1907	332,452	48	332,500	8.7	554,450	34,940,600	....
12 months ending Aug. 31, 1908	147,321	279	147,600	8.8	240,409	14,825,000	....
12 months ending Aug. 31, 1909	359,257	118	359,375	9.1	531,298	33,667,400	....
12 months ending Aug. 31, 1910	342,615	685	343,300	10.1	432,760	26,746,600	....
12 months ending Aug. 31, 1911	347,827	13,373	361,200	10.6	624,765	35,180,040	497,480
12 months ending Aug. 31, 1912	374,030	27,270	401,300	11.2	726,686	44,710,880	2,375,800
4 months ending Dec. 31, 1912	124,446	8,354	132,800	10.8	230,451	15,041,920	1,557,440
	2,276,565	50,141	2,326,706	9.7	3,756,795	230,924,640	4,430,720

The ore that is now being mined comes almost wholly from the Morning vein, which is about 11,000 feet north of the portal of tunnel No. 6. A relatively small amount of ore is being taken from the You Like vein, about parallel to the Morning vein and 1,000 feet south of it. At least two other veins are cut by the tunnel, but neither shows much promise at the intersection and neither has been developed. The portions of these veins that are being worked are chiefly in the ridge between Mill Creek and Grouse Gulch. In 1904 both productive veins were reached by tunnel No. 5, between whose portal on Mill Creek and the mill, which had its present location, ore and supplies were hauled by a narrow-gage surface railway. The present adit, tunnel No. 6, which runs nearly north under the crest of the ridge, was completed in 1906 and transportation is now effected by powerful electric motors, which bring the ore directly to the bins. The equipment both on the surface and underground is impressively substantial.

The mill is perhaps the most interesting in the Cœur d'Alenes, but only its salient features can be touched on here. It comprises two virtually separate plants. In one the galena is concentrated by gravitational methods; in the other sphalerite, which, being of nearly the same specific gravity as siderite, is not amenable to such methods, is concentrated by flotation. The processes employed to save the galena are highly elaborated and involve repeated grinding, much of the material being finely ground in Hardinge conical pebble mills. The Macquisten flotation process [1] is the one employed to save the sphalerite. The mill losses of both lead and zinc are still considerable. They are probably carried off for the most part in the large amount of slime which results from the repeated grinding. At the time of visit experiments were being made on other flotation processes, which

[1] Described by O. B. Hofstrand, Bull. Am. Inst. Min. Eng. No. 73, 1913.

are likely to be installed in the near future and to result in a much higher saving than that hitherto obtained.

The workings above tunnel No. 5 are now inaccessible, and the level of that tunnel is the datum from which the depth of later workings is reckoned. Seven levels have been driven on the Morning vein at intervals of 200 feet below tunnel No. 5. Tunnel No. 6 is on the 800-foot level, and the lowest depth attained is 850 feet lower, where a station was being cut out at the time of the recent visit. The lowest stopes are on the 1,450-foot level, which is about 2,600 feet below the highest stopes and nearly 3,000 feet below the highest point of the outcrop. On the You Like vein there are drifts at 200-foot intervals down to the tunnel level, below which the vein has not been followed.

GEOLOGIC CONDITIONS.

The Morning and You Like veins are both nearly vertical and strike about west-northwest. The rock in which they occur is quartzite that varies considerably in hardness, purity, and thickness of bedding but which apparently all belongs to the Revett quartzite. Some of the purest and thickest-bedded quartzite is exposed in the west You Like drift on the 800-foot level (No. 6 tunnel) and on the walls of the great station on this level near the Morning lode. Even this quartzite is for the most part somewhat sericitic, however, and most of that adjacent to the lode is distinctly so. On the whole the most sericitic and flaggy rock is that in the eastern part of the mine, which probably belongs to the uppermost part of the Revett quartzite. No igneous rock was observed in the walls of the vein in the workings now accessible, although a small lamprophyric dike appears in the eastern part of the workings and another basic intrusion is cut in the outer part of the tunnel.

The bedding of the country rock near the veins is steeply inclined and remarkably variable in strike, as if the strata had been raised to a nearly vertical position by pressure in one direction and afterward crumpled by pressure acting nearly at right angles to that direction. The general strike is a little west of north and the general dip easterly, so that the rocks in the eastern part of the mine are the youngest. The ore bodies occupy narrow shear zones rather than sharply defined fissures. Considerable attention was given to the question of how much movement these shear zones represent. The presence of gouge along the slips in the lode and adjacent country rock is proof of some displacement, and the difference in the character and attitude of the rocks on either side of the veins is in many places so sharp as to suggest that the amount of this displacement may have been considerable. With respect to the Morning vein this suggestion could not be definitely confirmed, and the sharp, steeply pitching folds visible in the crosscut between the two shafts show, indeed, how the observed relations might be explained without faulting. On the You Like vein appreciable faulting has demonstrably occurred, for near its intersection with the tunnel, where it is narrow and well exposed in the roof, the beds on either side clearly fail to match. It is not probable, however, that the movement on either vein has been comparable in magnitude with that of most of the faults shown on the geologic map of the district.

Fractures transverse to the veins are neither numerous nor important except in the extreme eastern part of the mines. Here the You Like vein in particular is thrown a few feet by several small faults whose general strike is about north-northwest to north-south. The vein is farther north on the east side of most of the faults than on the west side. These small faults are probably subsidiary to a larger one, recognized in 1904,[1] which brings the Newland formation on the surface against the Revett. It is shown on the map accompanying Professional Paper 62 as striking about northwest, but its true strike appears on review to be more nearly north and south. A thin basic dike parallels the fault a few yards to the east. The ground east of the Morning mine has been well prospected without revealing any vein comparable in size to the Morning vein except the Hunter lode, which is so far south that its correlation with the Morning vein is at least highly questionable, for it would postulate a horizontal displacement of about half a mile.

CHARACTER OF THE ORE BODIES.

The Morning vein is essentially simple in structure except for a large horse, which was noted in the previous report. In a great cave on the 200-foot level the horse is about 35 feet wide and each of the two branches of the vein is about 10 feet wide. The length of the horse is about 800 feet in the upper workings. This horse apparently persists downward nearly to the 1,000-foot level, where two branches of the vein appear to have coalesced, and here the stopes have their maximum thickness of about 40 feet. The vein is described by Ransome as being inconspicuous and practically barren where it is cut by tunnel No. 5, and it has the same unpromising character at its intersection with tunnel No. 6 but widens in both directions from that point.

The You Like vein is of simple tabular form without large inclusions. Its thickness is considerably less than that of the Morning vein, being at the maximum about 10 feet.

The ore of the two veins is alike in most characteristics. Its chief constituents are shown by analysis by the chemists of the company to be present in approximately the following proportions: Siderite, 50 per cent; quartz, 25 per cent; galena, 11.5 per cent; sphalerite, 11 to

[1] Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 166.

12 per cent; calcite, 3 per cent; pyrite, less than 1 per cent. In addition, small quantities of barite, magnetite, chalcopyrite, tetrahedrite, and probably pyrrhotite are present, the barite being locally abundant and conspicuous. Magnetite and chalcopyrite are nowhere easy of recognition. The quartz probably belongs in part to the country rock. The vein structure shows that it was only partly formed by the filling of fissures and partly by replacement of the wall rocks. Its limits are not sharp, although the limit of commercial ore is fairly definite, and there are discontinuous subsidiary veins which are too small to mine. The ore presents widely varying degrees of richness. Some of it consists of solid masses of galena and sphalerite almost unmixed with gangue, and in some the minerals are disseminated in country rock.

A more or less distinct banding is characteristic of the veins as a whole, but the bands are discontinuous and irregular and afford no obvious clue to the order in which the minerals were deposited. The Morning vein is cut by longitudinal slips, some of which are very persistent. The following is a section across one of the richest parts of the Morning vein on the 1,400-foot level. The bands are named in order from north to south.

Section of Morning vein.

	Feet.
Sheared quartzite, vertical and striking about northwest, with a little ore.	
Ore (galena and sphalerite)	½–1½
Sheared country rock and ore in nearly equal parts	1
Ore with a little siderite, quartz, barite, and country rock	1
Ore (galena and sphalerite, intimately mixed, with almost no gangue)	7
Smooth slip, vertical and striking N. 60° W.	
Ore with much siderite, etc	1
Crushed country rock with a little ore	1
Ore, medium grade, rudely banded, with small transverse faults	1½
Lean ore (crushed country rock with stringers)	1½
	15
Slip, vertical, N. 45°–55° W.	
Crushed quartzite, nearly barren.	

STAR MINE.

The Star mine, owned by Messrs. Finch, Campbell, Moffatt, and others, is in Grouse Gulch at the foot of the spur between its principal forks. It is of interest because it shows what are believed to be the westward continuations of the Morning and You Like veins. It is developed by a tunnel about 3,500 feet long and by several very extensive drifts.

The sedimentary rock penetrated by these workings is quartzite, some of which is extremely hard and thick bedded and all of which probably belongs to the Revett quartzite. The drifts cut several small dikes of a gray porphyry and a dark lamprophyre, both of which probably bear a genetic relationship to the monzonite that is exposed near Gem, about 2 miles to the northwest. The general dip is about 70° E., but the strike is extremely variable. Fissures, mostly of northwesterly trend, are very numerous.

The best showing is in the Morning vein east of the main tunnel, which in places contains 4 feet of fairly good concentrating ore. A widening of the vein is apparent in some places where it is joined by other fissures formed prior to the mineralization, and some vein material makes off in fissures of this character. In the easternmost accessible workings the vein seems to have divided into several small branches. A vertical fault converging westward with the vein has cut it off a short distance east of the tunnel, but its westward continuation is believed by Mr. Moffatt to be represented by a vein found at the face of the tunnel. The study on which this paper is based hardly suffices to prove or disprove this supposition. The fault, however, though very distinct, is probably not of large throw, for it has displaced a porphyry dike which it cuts only about 20 feet. A long drift in the general direction of the Morning vein west of the tunnel has not revealed any commercial ore. It follows here one and there another of a system of sinuous branching fissures, among which it is difficult to identify the representative of the Morning vein. The conditions along the drift that goes westward on the supposed You Like vein are somewhat similar, although this drift follows a straighter and more definite fissure along which some faulting has clearly taken place.

A short drift has also been run westward on a fissure intermediate between the Morning and You Like, but it reveals little, if any, ore. It perhaps corresponds with a fault that is very conspicuous on the surface.

The ore from the Morning vein contains galena in a gangue consisting chiefly of quartz with very little siderite. It is accompanied by small amounts of sphalerite and pyrite. The scarcity of siderite here is a notable contrast to its abundance in the Morning mine and seems to illustrate the general rule first deduced by Ransome,[1] that this mineral becomes less abundant in the veins as the monzonite is approached.

GOLD HUNTER MINE.

ECONOMIC FEATURES.

The lode worked in the Gold Hunter mine (commonly called simply "The Hunter") is about 1 mile northeast of Mullan, in the ridge between Mill Creek and Hunter Gulch. In 1904, when the mine was

[1] Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 136-137.

visited by Ransome,[1] the working adit was tunnel No. 5 in Hunter Gulch, but the present adit is tunnel No. 6, whose entrance is at the mill near the South Fork of Cœur d'Alene River, on the east edge of Mullan. Through this tunnel, which is nearly a mile long, ore and supplies are transported in and out of the mine by electric motor.

No figures of production for the years subsequent to 1906 are available.

The lowest workings in 1904 were 200 feet below the level of tunnel No. 5, which is about 4,000 feet above sea level. The adit, or tunnel No. 6, is about 400 feet lower than No. 5, and drifts have been run at 75, 205, 285, and 405 feet below the adit. At the time of the recent visit a small amount of stoping had been done on the 205-foot level and almost none below it.

The amount of ore mined per day at the time of the recent visit was about 340 tons. In the mill about 40 tons a day is picked out of the sorting belt as waste and crude ore, the crude ore amounting to about 3 tons a day. The bulk of the ore is concentrated by means of Hartz jigs, Wilfley tables, and Frue vanners. The constitution of much of the ore necessitates fine grinding, which is accomplished by means of Huntington mills. The only unusual feature of the process is the saving of an iron concentrate, which is used as a flux and which contains more silver than the average ore. No zinc is saved, and the proportion of that metal is kept below 10 per cent, so that no penalty is exacted at the smelter.

GEOLOGIC FEATURES.

Rocks and structure.—Review of the surface exposures and study of the tunnel section, which was not available in 1904, afford a basis for some correction of the mapping in the vicinity of the Hunter mine. The principal error relating to this vicinity in the map accompanying Professional Paper 62 is the ascription of the country rock of the lode to the St. Regis formation; it belongs in reality to the lower part of the Newland formation, as was suspected by Ransome.[2]

The principal structural feature in the outer part of the tunnel is a synclinal fold with St. Regis rocks in the trough and Revett quartzite on the sides. This main fold is much complicated by minor plications and by fractures, on many of which there seems to have been thrust faulting with upthrow on the north side. The north side of the syncline abuts against one of the most persistent faults of the district, the White Ledge fault. Where it intersects the tunnel this has a nearly east-west strike and is nearly vertical. It marks a fairly sharp change in the country rock, that on the south being rather hard and thick-bedded quartzite and that on the north a fine-grained pale-green, somewhat calcareous slate. Otherwise the fault might

[1] Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 168. [2] Idem, p. 169.

easily be overlooked, for it is extremely tight and inconspicuous, although its throw at this point can not be less than half a mile. The rock immediately north of it in the tunnel probably belongs to the lowest part of the Newland formation, for it is succeeded within a short distance by dull-purplish slate alternating with green bands, belonging to the St. Regis formation. These rocks in turn are cut off on the north by a fault whose throw is probably less than that of the White Ledge fault, yet great enough to bring bluish-banded slate of the middle part of the Newland down against the green slate of the lower Newland. This fault, which is a normal one dipping about 40° N., is probably identical with one that crosses Paymaster Gulch near its mouth and is therefore designated the Paymaster fault. The greenish slate of the lower Newland reappears, however, a short distance north of the fault and is the country rock of the Hunter lode. Another fault bringing middle Newland down on the north is shown by surface indications to cross the ridge about 400 feet north of the lode, but this has not been penetrated by the mine workings. The general dip of the beds north of the White Ledge fault is southward and very steep.

The sedimentary rocks in the tunnel are cut by several small dikes of a black fine-grained rock whose most prominent constituent is hornblende in the form of minute needle-like crystals. None of these dikes are seen in the lode, and their relation to the ore is consequently unknown.

Form of lode.—The Hunter lode is more complex in structure than most others in the Cœur d'Alenes, a character probably due to the unusual fissility of its country rock. On the No. 5 tunnel level and above, where it was studied by Ransome, the lode comprises three important veins. In the workings now accessible there are only two principal veins, whose precise relation to the three of the upper workings is not clear. The workable ore bodies are ramified and ill defined, and much ore is distributed in masses too small and discontinuous to be minable. The commercial mineralization is confined to a zone that is about 100 feet broad on the adit level, but the total breadth of the mineralized zone is about twice as great. The total length of the productive zone is about 640 feet in the active workings, and the maximum length of any individual slope is about 300 feet.

At least five ore bodies are exposed in the present workings—two in the north vein and three in the south. The general pitch of all the shoots is nearly vertical.

The largest ore body is probably the northwest one, developed by the "Ryan crosscut" stope above the adit level. In a part of this body there was about 40 feet of good ore, but the stope length of the broad part is only about 50 feet. On the east end the vein is split by a horse into two wings, both of which contain good ore; on the west the same condition seems to exist, but here only the north wing is minable, so that in effect the vein narrows abruptly in this direction. The cause of this narrowing, locally referred to as a "break," is not very obvious. The "break" does not coincide with any clean-cut fault, separating good ores from barren country rock, but is merely a rather abrupt change from commercial ore to poor ore. Close examination shows, however, that such "breaks" coincide approximately with fissures striking about N. 30°-40° W. The broad part of the ore body was therefore probably formed by replacement of the prism of shattered rock produced by the intersection of two zones of fissuring. The outlines of the stopes suggest that there was some slight displacement of the veins on the cross fissures, but its effect is blurred by subsequent mineralization and by the lack of definition in the ore body. The vein is not seriously displaced by cross faults in any part of the mine. The northeast ore body, opened by the "north stope," shows a similar branching into "wings." The north and Ryan crosscut stope are connected on the higher levels.

The most southeasterly ore body was worked in the "iron stope," probably so called because of the large proportion of pyrite it contained. This body was not over 10 feet wide in the accessible workings and tapered out a short distance below the No. 5 tunnel level. The principal ore body of the south vein is in the south-central part of the workings. It is developed in the bench stope, which extends upward from the adit level into the old abandoned levels, and the so-called "south stope" that extends 200 feet below the adit level is evidently in a downward continuation of the same shoot. The Ryan stope, a little farther west on the south vein, extends about 100 feet up from the No. 6 tunnel level, and some work has been done on the lower levels in what appears to be the same relatively small ore body.

Although ore has been found on the lowest levels yet attained, little exploration has been done on these and the quantity of ore available below the adit tunnel is unknown.

Character of ore.—The chief valuable constituent of the Hunter ore is galena, and the gangue is chiefly siderite. Quartz and barite are other abundant gangue minerals, barite being more abundant than in any other producing mine of the region. Metallic sulphides of minor economic importance, though occurring in considerable quantity, are sphalerite and pyrite. Pyrite is rather more abundant than in most other mines of the district and seems to be particularly so in the margins and ends of ore bodies. Sphalerite is certainly less abundant than in the Morning mine and has shown no very notable increases with depth. Stibnite is widely though unevenly and sparsely distributed and is invariably inclosed in quartz. Tetrahedrite, which has been an important constituent of the ore in the mine as a whole, is said to occur in the lower levels.

Conspicuous banding roughly parallel to the walls is rather more characteristic of this lode than of others in the Cœur d'Alenes. The bands, few of which individually are more than a foot thick, are distinguished by prevalence of siderite, quartz, country rock, or barite as the matrix of the ore minerals, and also by the varying abundance of the ores. The best ore now being mined is a streak of barite and galena along the north side of the north vein. For the width of a foot or two in many places these two minerals alternate in irregular bands with little admixture.

ALICE MINE.

The Alice mine is located in Ruddy Gulch, about half a mile north of the South Fork of Cœur d'Alene River. The workings of this mine consist of a main adit on the 100-foot level; 200, 400, and 600 foot levels; a shaft; and a short surface tunnel known as the Mud Tunnel. At the time of visit the 600-foot level was inaccessible because of water in the shaft. The mine is worked from the shaft, the tunnel on the 100-foot level being boarded up and apparently long in disuse. The tunnel, however, affords an interesting geologic section. It starts south of the Osburn fault, which it crosses about 300 feet from the entrance. Up to the fault the tunnel is driven in a banded blue and black shale interbedded with quartzitic layers, belonging to the Newland ("Wallace") formation. Toward the fault the formation, which near the tunnel entrance presents a fairly regular dip, becomes crushed, folded, and faulted. North of the fault the tunnel enters into hard brecciated quartzite, which is thought to be Revett. Here again the characteristics of the formation are somewhat masked by shearing, brecciation, and silicification. All the other workings of the Alice mine are situated north of the Osburn fault. On the 400-foot level two drifts have been run to the fault, but at the time of visit the loose ground had caved and the drifts were inaccessible.

The ore occurs in three veins or, more properly, brecciated zones in the quartzite. These veins are known as the Alice, Mary J., and Mud Tunnel. The Alice and Mary J. veins are approximately parallel to the Osburn fault, but the Mud Tunnel vein makes a small angle with the Mary J. These brecciated zones are of no great persistence along either their strike or their dip. Numerous small faults and slips run through the brecciated quartzite in various directions. Some of them cut the ore off sharply, or the deposit may be limited by two intersecting slips, which are the walls of the vein. The Mary J. vein, which has been stoped on the 100 and 200 foot levels, has not been disclosed by the development work on the 400-foot level. The Mud Tunnel vein, which is exposed in the short surface tunnel and on the 100-foot level, has not been encountered in the lower workings. The Alice vein, however, persists to the lowest workings of the mine. The workable parts of these veins are of small extent, the ore occurring in bunches or lenses. The Alice vein, for instance, which on the main level has been followed for over 1,000 feet, has been stoped in but two places, one stope being about 100 feet long and of slight vertical extent, and the other a very small stope in which the ore was extracted from the trough of two intersecting faults. The Mary J. vein has been stoped for a distance of 100 feet along the strike and through a vertical distance of 95 feet. Other stopes have been made on the several levels. A stope on the Alice vein on the 400-foot level is said to have produced ore to the value of $70,000.

The ore deposits in the brecciated zones consist of metallic sulphides and quartz veins. The principal sulphide is galena, but green stains on the walls indicate the presence of copper. The galena occurs both as replacement deposits and as narrow fissure fillings in the brecciated quartzite. It does not seem to be a constituent of the quartz veins proper, although secondary silica is prominent in the mineralized zones. In places the ore bodies are from 12 to 14 feet wide and have a lead content of 8 per cent. Cerusite is another ore mineral of these deposits, and probably equals the galena in amount. The mineral owes its presence to the porous nature of the brecciated quartzite. It was noted on the 400-foot level and is said to extend to the deepest workings. Siderite does not occur in the mineralized zones, the Alice being the only lead mine in the Cœur d'Alene district in which siderite is not an abundant gangue mineral.

Several periods of movement are apparent in the mineralized zone in the Alice mine. An idea of the disturbances accompanying and subsequent to the mineralization is best gained by a study of the Mary J. vein on the 200-foot level. The vein is about 12 feet wide in the center of the stope but narrows toward the east and west ends. The north wall of the vein is a slickensided plane trending N. 60° E. and dipping 80° S. Against this wall a narrow seam of black gouge shows ground galena, then follows a barren quartz vein about 2 feet thick, and next is the ore, consisting of brecciated quartzite in which occur seams of galena and its oxidized products, along with the secondary silica. On the south wall another slip dips to the north and strikes in such a direction as to cause a thinning of the ore body to the west, as well as to limit it in depth.

The ore is concentrated at the mine. A mill with a capacity of 125 tons a day was, at the time of visit, treating 75 tons a day. Owing largely to the absence of siderite and sphalerite in the ore, the mill treatment is simple and a saving of 75 to 85 per cent of the valuable metals is effected. The ore is crushed, screened, and first treated on jigs. The middlings from the jigs are reground and treated on Wilfley tables and Frue vanners. The concentrates consist of galena and cerusite.

VINDICATOR PROSPECT.

The lower tunnel of the Vindicator prospect has a conspicuous dump at the side of the railroad a few rods east of Deadman Gulch, and there is another tunnel about 300 feet uphill to the north. The upper tunnel has tapped the vein at a distance of 225 feet from the portal. The vein as there exposed has a maximum observed thickness of about 1 foot and is ore bearing for a length of at least 60 feet; it contains some fairly good galena ore in a gangue consisting chiefly of quartz. High returns in silver are said to have been obtained from the oxidized ore near the surface. The vein follows a zone of fissuring along which there has been considerable postmineral movement. The country rock is green slate belonging to the Newland or the St. Regis formation. The strike of the vein is east and west and the dip about 50° N., its attitude being but slightly different from that of the stratification.

The lower tunnel, although it is about 1,000 feet long and has passed well beyond the point at which it should intersect the ore body if the attitude of the vein in the upper tunnel persisted downward, has not reached a vein, nor even any fissure that appears to represent the vein as known above. The failure of the vein to appear in the lower tunnel is probably the result of faulting. A normal fault with relative upthrow on the north would evidently displace the vein in such a fashion that its north segment would be farther north on the tunnel level than if no faulting had occurred; and if the displacement were of this kind, the vein should be reached by a prolongation of the tunnel. It is possible, however, that the movement was in the contrary direction and that the north segment of the vein may be below the lower tunnel. Present knowledge hardly warrants a decided opinion as to the more probable direction of displacement, but some further exploration to the north appears to be warranted. It is of course uncertain whether the ore body if found would prove large enough to be workable.

PACKER CREEK AREA.

GENERAL FEATURES.

The Packer Creek area comprises a large number of prospects distributed along the trench determined by the Osburn fault zone. The deposits of this area are fissure veins of the same physical character as those at Mullan, and their mineralogic features resemble to a certain extent those of the Mullan area. Galena is the most generally distributed mineral, but argentiferous tetrahedrite is relatively more abundant than near Mullan, and the silver tenor is correspondingly high. Copper and gold are also present in appreciable quantity. The copper seems for the most part to be a constituent of tetrahedrite but is partly in chalcopyrite. The usual gangue minerals of the area are siderite and quartz, but at least one baritic vein occurs; this, however, has not been explored sufficiently to demonstrate its value.

The most fully developed properties of the area are on either a very narrow zone or a single fissure extending parallel to the general direction of the trench and north of the main fault. The country rock of this lode apparently belongs for the most part to the Burke formation but probably comprises some Revett quartzite. The structure is complex and characterized by extreme crushing. The Last Chance property, which typifies these deposits, is the only one that has shipped much ore; it is reported to have made a net profit of about $200,000 but is now idle. To the east of it are the Ben Hur, Bell, Tarbox, and Meadow Mountain, showing similar ore; to the west are the Bryan and Syndicate, less clearly related to it in character and structure.

A somewhat isolated deposit, which is discussed with those of the Packer Creek basin for convenience, is that of the Silver Cable mine, which contains a high proportion of zinc.

SILVER CABLE MINE.

The Silver Cable property is near the head of Brimstone Creek, a short distance northeast of the pass at the head of the old valley. It is developed by means of three tunnels. The country rock of the ore body is gray sericitic quartzite, which apparently belongs to the Burke formation. The general strike of the bedding is about east-west and the dip steep, being in places overturned. The vein strikes a little north of east. Its ores are chiefly galena and sphalerite; a little tetrahedrite is said to be present, but pyrite is scarce. The ore resembles that of the Morning vein more than that of the principal prospects in the Packer Creek basin. An assay of representative ore is said to give 11 per cent of zinc and 24 per cent of lead.

The best showing of ore is in the highest tunnel, where there is a well-defined vein about 4 feet thick, with some small horses. The vein is partly oxidized on this upper level, and some cavities in it contain a good deal of well-crystallized lead carbonates. On the intermediate level the ore is less abundant and comparatively little work had been done prior to our visit, but exploration was being pushed there at that time and is reported to have met with some success. On the lowest level the main crosscut did not show any ore; the lode was picked up in a drift to the northeast but apparently dies out toward the east.

SYNDICATE PROSPECT.

The Syndicate prospect is on Rat Creek, 1 mile west of the Bryan mine. The workings consists of an adit 225 feet long, whose average course is N. 75° E., and several drifts extending in a northerly direction aggregating 300 feet in length. The country rock is hard white and greenish sericitic quartzite, greatly crushed and faulted. A quartz-siderite vein from 3 to 6 feet wide, which strikes N. 75° E. and dips vertically, is exposed in the adit but is cut off at the face by a northwestward-trending fault. A band of ore from 6 to 8 inches wide on the north wall of the vein contains tetrahedrite, chalcopyrite, galena, and pyrite. The ore is said to yield high returns in silver.

BRYAN MINE.

The Bryan is one of the more extensively developed properties in the basin of Packer Creek, although it has not made shipments. It is on a tributary of the West Fork of Packer Creek, at the end of a wagon road from Saltese, about 5 miles distant. It has three adits, with a vertical range of about 500 feet. About 2,500 feet of horizontal work has been done, and the lowest tunnel is connected with the one above by a raise.

The country rock penetrated by these workings consists of more or less sericitic quartzite, and probably represents both the Burke formation and the Revett quartzite. The structure is too complex and too imperfectly understood to be characterized satisfactorily and briefly. The beds dip steeply, and are considerably folded. In places they are traversed by broad zones of crumpling and mashing as well as by more sharply defined fissures, most of which have a northwesterly strike.

The principal vein strikes about N. 60° E. and has a steep dip to the south. Its chief gangue mineral is siderite, which is cut by small veins of quartz. The ore minerals are pyrite, galena, and gray copper. The maximum thickness of this sideritic vein is about 5 feet, but in places it pinches to a thin dark seam by postmineral shearing. In the highest tunnel (No. 1) this vein is cut off on the east by a fault of northwesterly strike and a dip of 45°–65° NE. The displacement caused by this fault is not known. It has not been identified with certainty on the lower levels; a fault of similar direction is followed by a drift on the No. 2 level, and this causes only a small offset of the east segment to the north. The fault has apparently not been cut on the lowest level. Difficulty in the discussion of this fault is caused by the lack of an accurate mine map.

Some of the richest ore is not obtained from the main vein but from a smaller branch, which has been followed in the raise. Some ore in the raise is said to assay 38 per cent of lead and 16.8 ounces of silver to the ton, but these figures would not be representative of the vein as a whole.

U. S. MINE.

The U. S. mine is just across the gulch from the Last Chance and on the same lode. It is of interest as having produced some ore, but it is now abandoned and its lower workings are inaccessible. The upper tunnel shows a vein about 4 feet in maximum thickness, which pinches out in places between two strong gouges. The country rock is quartzite of the Burke formation, thoroughly crumpled and shattered. The vein matter is strongly oxidized, being apparently similar to that of the Last Chance.

LAST CHANCE MINE.

The Last Chance mine is located on a tributary of Packer Creek about 3 miles north of Saltese. The workings consist of two tunnels, an intermediate level, a shaft, and several open cuts, but the only accessible entrance to the mine is through the main tunnel, which is probably 200 feet below the outcrop of the south vein. The forest fires of 1910 destroyed the entrance timbers to the other mine workings, so that caving has resulted, and although parts of the upper workings are still accessible from raises in the lower level, the caved condition of many of the workings leaves much to be inferred in regard to the rock structure. No work has apparently been done in the mine for several years. The main tunnel trends N. 70° E. for 275 feet and then branches, each branch in turn having several drifts. Two veins or probably faulted members of the same vein occur, one in each branch of the tunnel workings. A considerable quantity of ore has been stoped from each of these ore bodies above the main level. The production of the mine is said to be in excess of $200,000.

The structure is complex. The green thin-bedded quartzites of the Burke formation are extremely folded and faulted. In general the formation strikes northwesterly with steep southerly or vertical dip, but flat-lying and northward-dipping beds were also observed. The veins have undergone the same deformations as that of the quartzite beds. In a raise from the south branch of the main tunnel the vein strikes east and west and has a vertical or steep southerly dip, but on the main level it conforms to the flat-bedded structure except where it is cut off by a northwestward-trending fault. In the north branch the vein strikes N. 50° W. and has a vertical dip.

The ore of the Last Chance consists of galena, pyrite, tetrahedrite, and stibnite in a gangue of quartz and siderite. The outcrop of the deposit shows the oxidized products of these ore minerals in spongy limonite. Galena is the most abundant mineral. The antimonial compounds are sparsely distributed but where present give a high tenor in silver. The average ore is of high grade and is valuable chiefly for its lead and silver content.

BEN HUR PROSPECT.

The Ben Hur property is on a small tributary of Packer Creek about 3 miles north of Saltese and occupies the ground covering the vein between the Last Chance and Bell prospects. The workings on the Ben Hur consist of three tunnels, two of which, situated near the outcrop of the vein, have not been worked for several years and are now inaccessible. A 1,100-foot tunnel taps the vein several hundred feet below the lead of the upper workings. The developments on the vein, which strikes about N. 70° W., consist of west and east drifts. In the west drift work has been discontinued and the ground is caved in several places, but the east drift was being extended at the time of visit.

The greenish sericitic quartzites of the Burke formation are well exposed in the tunnel section. They show intense folding and faulting, to which is attributed the shalelike appearance of the quartzites. A syncline is apparently exposed in the tunnel, as north and south dips were noted on the sides of a greatly contorted zone in which are flat-lying beds.

The mineralization revealed in the lower workings consisted of the deposition of irregular bunches of quartz and siderite and the replacement of a quartzite bed, along a fault plane, by fine-grained sulphides and secondary silica. The impregnated quartzite bed is about 8 inches wide and is fairly regular in width in the east drift, but its form in the west drift could not be determined because of the timbering in that portion of the mine. Stibnite, galena, pyrite, and chalcopyrite were noted in specimens from this vein. Of these minerals stibnite is the most abundant. The minerals are strained in appearance owing to movement along the fault. No assay of this ore was made, but it is said to carry silver. Specimens from the dumps of the upper workings indicate ore entirely different from that of the vein in the lower tunnel but very similar to the ore from the Last Chance, Bryan, and other prospects on this vein. Galena and cerusite in porous limonite resulting from the oxidation of siderite were noted, but the antimonial minerals, stibnite and tetrahedrite, were not observed. This property has made no ore shipments.

BELL PROSPECT.

The Bell prospect is a short distance east of the Ben Hur. The workings are not extensive on this property and are now inaccessible owing to fire and caving. The oxidized ore on the dump contains scattered pieces of galena. The surface showing is very similar to those of other prospects situated on this vein.

TARBOX MINE.

The Tarbox mine is on the west side of the Middle Fork of Packer Creek, about 3 miles from Saltese. A 500-foot shaft has been sunk on the vein, but the mine buildings were burnt in 1910 and the mine has since been idle, its shaft being filled with water. The ore on the dump is of the same general character as that in the Last Chance and Bell properties; it consists mainly of siderite, quartz, galena, and pyrite.

MEADOW MOUNTAIN.

The Meadow Mountain property is in a small gulch tributary to Packer Creek, about half a mile north of the prominent isolated hill after which it is named, in the same zone of mineralization with the other principal prospects of Packer Creek basin. It is developed by five adits, in only two of which has any considerable work been done.

The country rock consists of grayish flaggy sericitic quartzite, which probably belongs to the Burke formation. The general strike is northwesterly. The most remarkable geologic feature is the prevalent crushing, buckling, and contortion of the strata. A crosscut on the No. 5 level extends northwestward more than 300 feet beyond the vein in soft muck, showing traces of bedding only here and there. No walls to this great breccia were found; it is not even clear in what direction the zone of crushing trends.

The workings appear to cut two veins. The more southerly contains much pyrite and is apparently of low grade. A little stoping has been done in the north vein, which shows some good galena ore. This vein appears to be much faulted and has not been followed for more than 100 feet. The present development, however, is not sufficient either to prove or to disprove the value of the property.

BARITE VEIN.

A vein consisting chiefly of barite runs about parallel to and a few rods north of the West Fork of Packer Creek and has been opened by several shallow prospect holes. The vein is apparently a little over a foot thick. Rusty cavities and masses of limonite in the barite probably represent siderite for the most part. The vein shows no ore in the weathered portion thus far explored, but the association of galena with barite near Mullan is common enough to encourage deeper prospecting.

HEMLOCK PROSPECT.

The Hemlock property is on the West Fork of Packer Creek near its mouth, about a mile and a half distant from Saltese. It is well south of the zone on which the Bryan and Last Chance mines are located. The country rock is grayish impure quartzite, which probably belongs to the St. Regis formation. The main development is a drift extending about 300 feet along a vein whose strike is almost exactly east and west. A spur to the south near the portal enters an apparently distinct vein, but this is probably the same vein repeated by faulting. The vein is affected by other minor faults.

The portion of the vein exposed in the principal drift has an average thickness of about 20 feet, and it is apparently about twice as thick as this in the outer part. It is of the common sideritic character and makes a dark-brown gossan, which is exposed in the road cutting. The siderite is cut by small veins of quartz. The underground workings show that some galena is inclosed in both siderite and quartz and that the lead sulphide forms little stringers in the quartzitic country rock, as it so commonly does in the Cœur d'Alene mines. Considerable pyrite is present. The ore as yet in sight is of low grade, but the showing warrants further development.

SOUTHERN COPPER AREA.

TYPICAL FEATURES.

Most of the ore deposits south of Cœur d'Alene and St. Regis rivers are of a very simple type. They are well-defined, nearly vertical fissure veins in which the gangue is chiefly siderite, together with some other carbonates and a little quartz, and the primary ore chiefly chalcopyrite and pyrite. The country rock of most of them belongs to the Newland formation, though some are in the St. Regis. It is noteworthy and probably significant that this copper area is roughly coextensive with the area in which the Wishards sill is prominently developed.

The only property of this area from which ore has been shipped is the Monitor mine, a few rods west of the Bitterroot divide southwest of Saltese. The mine is now idle. Many claims have been patented within a few miles of the Monitor; of those in its near vicinity the St. Lawrence, Richmond, Alpina, and Alice are the most developed. Others farther southeast along the divide were not examined. There are evidently several nearly parallel sideritic veins in this vicinity.

Several prospects have been developed near St. Regis River, but some of these have not been visited. The Agnes prospect, south of Saltese, presents an isolated occurrence of galena. The prospects visited on Placer Creek, near Wallace, may be regarded as belonging in the same copper area, although one of them—the Vienna-International—is valuable chiefly for its lead.

An interesting fact of paragenesis observed in many prospects of this area is the clear priority of siderite to quartz. This is suggested by the presence of many quartz veinlets cutting siderite. It is strikingly demonstrated by the occurrence of abundant perfect siderite crystals, commonly 1 or 2 inches in diameter, partly embedded in quartz which has evidently filled cavities lined with druses of the carbonate. Chalcopyrite is inclosed in both quartz and siderite.

PROPERTIES NEAR SALTESE.

Monitor.—The Monitor mine has shipped about 500 tons of ore but has been idle since the summer of 1910, when the hoist and buildings were destroyed by fire. The workings are, therefore, not accessible, but the exposure in the throat of the shaft and the material on the dump give some information as to the character of the lode. The vein matter as exposed at the surface is a typical gossan—a soft, porous mass consisting mainly of limonite with some quartz and a little malachite in druses and along joints. The principal vein is nearly 15 feet thick and about vertical, though its walls are not quite parallel. It contains inclusions of the Newland country rock, which is also seamed by small subsidiary veins. The dump contains some oxidized ore that is richer in copper carbonates and some unoxidized ore showing chalcopyrite and pyrite in a gangue of siderite, calcite, quartz, and a white micaceous mineral.

Richmond.—The Richmond prospect is on a vein a short distance north of that exposed in the Monitor mine. It is developed by three shafts on the summit of the Bitterroot divide. The principal shaft is about 175 feet deep and a drift about 350 feet long has been run at the bottom of it. An adit was being driven, at the time of visit, from the west slope of the divide with the purpose of tapping the vein at a depth several hundred feet greater.

The vein is of the same general character as that of the Monitor mine and is thoroughly oxidized to the base of the present workings. The greater part consists of a paste of limonite derived from the decomposition of siderite. This is traversed by veins of quartz, mostly parallel to the walls, which enwrap pseudomorphs after siderite crystals. Joints and small cavities in the gossan are lined with malachite, but the copper content of the material seen is evidently small. The vein is from 5 to 10 feet wide, dips very steeply to the north, and strikes N. 75° E.

Copper Age.—The Copper Age property is developed by a tunnel just east of the divide and a short distance south of the Monitor mine. About 700 feet of the vein has been exposed. It is nearly vertical, strikes N. 65° W., and apparently has an average thickness of about 10 feet. The chief gangue mineral is siderite, which is not much oxidized, except in the outer part of the adit. A very little chalcopyrite and chalcocite is present.

Manhattan.—The Manhattan prospect, about 1¼ miles northwest of the Monitor mine, is developed by an adit and drifts aggregating 700 feet in length. It shows a large vein of siderite and quartz, in which no commercial ore was noted.

Alice.—The Alice prospect, on Kelly Creek, is developed by about 650 feet of drifts. The workings show two apparently distinct veins about 25 feet apart, which strike about N. 85° E. and dip 70° N. The north vein is the larger and attains a width of 6 feet in places. The veins show the usual character for this locality, the ore being pyrite and chalcopyrite, in a gangue of siderite, quartz, and calcite. It is mostly unoxidized. The tenor is rather low.

Alpina.—The Alpina property is also on Kelly Creek and taps a vein about 500 yards farther north than those of the Alice prospect. The adit is a crosscut about 300 feet long, and runs northward to a drift about 1,200 feet long. The vein strikes N. 85° E., dips 65° N., and is about 2 feet thick. The copper mineral is chalcopyrite, which is apparently more abundant than in the other prospects visited. The ore is said to assay well in gold.

Bald Mountain.—The Bald Mountain prospect is at the head of the South Fork of Dominion Creek, a short distance east of the Idaho-Montana boundary. The workings consist of an adit, 1,500 feet long, driven S. 35° W., near the end of which drifts extend to the south and east for several hundred feet. Banded shales and quartzites of the middle part of the Newland formation comprise the sedimentary rocks. The average strike is N. 34° W. and the dip 55° SW. From an excellent section in the adit the thickness of the Wishards sill was found to be 350 feet. The shales are metamorphosed to hornstones for 200 feet or more on either side of the sill. Several narrow fissures are exposed in the workings. In general they follow bedding planes, but one in the rocks, northwest of the sill, strikes east and west with apparently vertical dip, and this is occupied by a vein which carries chalcopyrite, sparsely disseminated, in a quartz-siderite gangue. The vein is several feet wide in the drift, but is apparently of no great persistence, as the extension of the strike of the vein in the adit shows only a few narrow siderite veins in a crush zone.

Switchback.—The principal opening of the Switchback prospect is just below the Monitor road and 2 miles southwest of Saltese. It consisted of a drift about 150 feet long at the time of visit. The country rock is green shale belonging to the lower part of the Newland formation. The vein averages only a few inches in thickness and consists principally of siderite with a little chalcopyrite. The ore is said to carry more than $2 a ton in gold. A tunnel 170 feet below the first one was being started at the time of visit.

Agnes.—The Agnes property is on Big Sunday Creek, about 2 miles south-southwest of Saltese. Its chief interest consists in the fact that it reveals an apparently isolated occurrence of galena in an area characterized mainly by copper deposits. The property is developed by three adits, in two of which the vein is shown; the third has not reached the vein. The total extent of the workings is about 800 feet.

The country rock is greenish slate of the lower part of the Newland formation dipping steeply southwestward. It is cut by many fissures, most of which strike about north-northwest.

The vein is composed mainly of siderite and quartz but contains a little irregularly distributed galena and chalcopyrite. Its greatest observed thickness is about 8 feet, but it varies considerably. In the middle tunnel the vein is clearly seen to be cut off, a short distance beyond the point at which it is first encountered, by a fault that strikes a little west of north and dips 80° W. In the south tunnel, which is about 20 feet lower than the middle one, the same fault is recognizable, marking a distinct change in the country rock; but the vein, though exposed in the outer part of the tunnel, was not traced as far east as the fault and appears to have pinched out.

Exploration has failed to find the vein east of the fault, but the work has not been done to good advantage. The work most likely to be successful would perhaps be the opening of a drift southward along the fault on the middle tunnel level, where the vein is largest. The wisdom of driving the north tunnel seems doubtful in view of present uncertainty regarding the position of the vein.

Taft.—The Taft prospect is on the south bank of St. Regis River a mile west of Taft. It is developed principally by means of a tunnel running S. 60° E. along a zone of fissuring. The most conspicuous fissure dips steeply to the south. The country rock belongs to the Newland formation. The fissure zone contains a little sideritic vein rock, but no sulphides were seen, although assay returns of $2 to the ton in gold and 2 per cent of copper are said to have been obtained.

Boston Colby.—The Boston Colby property is about half a mile west of Saltese, between the Northern Pacific and the Chicago, Milwaukee & Puget Sound Railway tracks. The workings consist of a tunnel driven S. 20° W. for 900 feet and drifts along a vein starting at a point 500 feet from the entrance and aggregating 450 feet in length. Near the intersection of the tunnel and drifts is a large excavation probably intended as a site for continuing development on the vein in depth.

The thick-bedded greenish quartzites with interbedded shales exposed in the tunnel probably belong to the St. Regis formation. They strike uniformly northwest and have an average dip of 50° SW. Two faults are cut by the tunnel, both of which lie in the bedding planes of the quartzite. One of these faults occurs at the end of the tunnel and is accompanied by gouge from 6 inches to 3 feet thick; the other is that containing the vein. Whether or not there has been considerable movement along these faults is difficult to determine because of the great similarity of the beds throughout the tunnel section. A strike fault has displaced a portion of the vein near the intersection of the tunnel and drifts.

The vein is from 4 to 10 feet in width in the west drift but in the east drift pinches out to a narrow gouge seam. The vein minerals consist of quartz, siderite, limonite, pyrite, and chalcopyrite. The siderite is largely altered to a porous mass of limonite, slightly copper stained, especially developed on the footwall side of the vein. The sulphides are sparsely distributed, and unless the ore contains considerable quantities of other metals than the copper it is probably too lean to be successfully milled. The deposit, however, as judged from the porous copper-stained limonite, may prove in depth to have a zone of enrichment.

PROSPECTS SOUTH OF WALLACE.

Several prospects are located along Placer Creek on or near a major fault which nearly coincides with that stream and can be traced for a long distance west. The workings here described are about 2 miles south of Wallace.

Vienna-International.—The Vienna-International, near the mouth of Flora Gulch, is the easternmost of these prospects. The workings consist of a shaft and two tunnels. At the time of visit the shaft was inaccessible and its depth was not determined. The tunnels are not over 700 feet each in length. The workings are all in banded shales and quartzites of the middle part of the Newland formation, which in general trend N. 50°-60° W. and dip 70° S. Several faults accompanied by gouge were noted in the bedding planes. The basis of the prospecting is a quartz-siderite vein from 3 to 5 feet wide, which strikes approximately east and west and has a vertical dip. The vein in the west drift of each tunnel was apparently cut off by a northwestward-trending fault. The ore on the dump, which apparently came from the shaft, shows scattered bunches of galena, pyrite, and chalcopyrite in a quartz-siderite gangue. The material seen, however, is apparently too poor to be concentrated with profit.

Castle Rock.—The workings of the Castle Rock property consist of a tunnel driven S. 35° W. for 565 feet, with a short drift to the west. The tunnel is for most of its length in thick-bedded white Revett quartzite. Near the end of the tunnel is a fault whose strike is N. 50° W. South of the fault are white banded quartzites with interbedded thin blue or black layers. The strike of this formation is N. 60° W. and the dip 60° N. North of the fault the Revett quartzite strikes N. 70° E. and dips 45° S. Two siderite veins are exposed in the tunnel. One near the entrance strikes N. 65° E., dips 75° S., and is 95 feet wide as seen in the section but probably about 40 feet wide at right angles to its strike. The vein is not homogeneous throughout but contains inclusions of quartzite. Siderite and pyrite are the most abundant minerals in the vein. Scattered bunches of chalcopyrite were noted, but the average copper tenor of the vein is probably low. Galena is said to occur in the vein, but none was noted. A shipment of 32 tons sent to the Pend Oreille smelter is said by Mr. Graham, one of the owners, to have yielded copper 2.61 per cent, lead 3 per cent, silver 3 ounces, gold $2.75, iron 34 per cent, a total value of $15.75. The other siderite vein, exposed near the end of the tunnel, is about 16 feet wide. It strikes N. 50° W. and has a steep or vertical dip. A little gray copper was noted in the seams of this vein.

Smart Aleck.—The Smart Aleck property is situated a short distance west of the Castle Rock. The workings consist of a short tunnel which follows a quartz-siderite vein, probably the same as that exposed near the face of the Castle Rock tunnel. The vein strikes about N. 60° W. and has a steep south dip. Its maximum width is 10 feet. Gouge occurs on the north or footwall side of the vein, and the association of minerals is the same as in the Castle Rock vein. The country rock on the footwall side of the vein is hard brecciated Revett quartzite.

Horn Silver.—The Horn Silver property is located about 1,000 feet west of the Smart Aleck. The workings consist of a rather irregular tunnel driven on a quartz-siderite vein. The vein strikes approximately N. 60° W. and dips 75° S. Crosscuts to the south disclose quartzite breccia followed by dark clay gouge of considerable thickness and next by bluish-black shales or slates with interbedded quartzitic bands, the formation being apparently similar to that seen south of the fault of the Castle Rock tunnel. The vein is of variable width and is not as well defined as in the Castle Rock. The maximum width is 10 feet. Massive white Revett quartzite constitutes the country rock on the north side of the fault.

WILLOW CREEK AREA.

GENERAL FEATURES.

The area designated by the above name, for want of a better, is a relatively narrow strip paralleling the river southeast of Mullan. It is characterized primarily by a peculiar alteration of the St. Regis country rock, which has been impregnated with chlorite and thus changed in color from the usual pale tints of green and purple to a rich dark green. This alteration is associated with and may be due to a thin basic sill which has been intruded into the St. Regis. It appears to have a genetic relationship to the formation of sulphides. The only prospects of this area studied during the recent visit are the Carbonate Hill and the Carny Copper. The ores of these prospects are sulphides of copper, iron, lead, and zinc, in a gangue whose most characteristic minerals are siderite and barite. The copper mineralization which allies this area to the southern copper area appears in the Carbonate

Hill prospect to be distinct from the lead and zinc mineralization by which it is allied to the Mullan area, but the relative age of the several ores was not determined.

CARBONATE HILL PROSPECT.

The Carbonate Hill property is on Willow Creek about 2 miles southwest of Mullan and a short distance south of the railroad. It was undeveloped in 1904 but now shows considerable promise of becoming a producer of lead and zinc. About 2,500 feet of work has been done on the property, as a result of which the lode is fairly well exposed.

The country rock of the deposit belongs to the St. Regis formation but is altered in the manner described on page 200.

The ore of the Carbonate Hill prospect does not form any continuous well-defined vein but is distributed in bunches and veinlets with a diameter that rarely exceeds 6 inches. The maximum breadth of the zone of commercial mineralization appears to be less than 20 feet, although it is difficult to estimate from present developments. The ore zone shows considerable fissuring about parallel to its west-northwesterly trend but no important cross fractures.

The chief valuable mineral in the ore is rather coarsely crystalline sphalerite of a pale resinous appearance. Galena is second in abundance. Chalcopyrite constitutes a rather small proportion of the ore, occurring chiefly in a single vein about 3 inches thick and free from the sulphides of zinc and lead. The principal gangue minerals are siderite and quartz, but calcite or dolomite and barite are also present. Pyrite is present in considerable quantity. The ore would mostly require concentration and presents the problem of economically separating sphalerite from siderite, the best solution of which appears to be offered by flotation methods.

CARNY COPPER PROSPECT.

The Carny Copper property is on the slope east of Willow Creek about opposite the Carbonate Hill. The principal opening is an adit about 1,500 feet long, which was hastily examined; there are higher workings which were not visited. The country rock belongs to the St. Regis formation and has in large part been colored a dark green by chlorite. A thin sill of basic igneous rock is penetrated by the inner part of the adit.

The vein differs considerably in character from the lode of the Carbonate Hill, being wide and well defined; it strikes east and west and dips steeply northward. The gangue minerals are siderite, quartz, and barite. The primary ore minerals found in the lower tunnel are chalcopyrite, pyrite, galena, and magnetite. The chalcopyrite is partly replaced by chalcocite. The magnetite is embedded in siderite, together with pyrite, and is notably abundant in parts of the vein. The most promising part of the vein is a baritic streak about 4 feet wide containing considerable galena, though hardly enough to constitute commercial ore. It is noteworthy that the lower tunnel shows considerably less copper ore and more lead than the upper.

SNOWSTORM COPPER BELT.

LOCATION AND PROPERTIES.

The Snowstorm copper belt runs northwestward along the south slope of the ridge north of the South Fork of Cœur d'Alene River at an average distance of about a mile and a half from that stream. Its only productive mine is the Snowstorm, the bulk of whose ore comes from a quartzite stratum about 40 feet thick, in which cupriferous sulphides and carbonates are disseminated. The copper-bearing stratum appears to extend for a considerable distance northwestward and is apparently tapped by the Snowshoe, Missoula Copper, and United Copper prospects; but its tenor is uneven and it has not yielded ore of proved commercial quantity and quality except in the Snowstorm mine. In the National tunnel of the United Copper property, however, it shows good promise. The Copper King prospect, farther west, is conveniently grouped with those mentioned because of its position and its copper content. It does not show, however, the continuation of the Snowstorm ledge and contains considerable galena, so that it may be regarded as illustrating the transition from the copper belt to the lead-bearing area. East of the Snowstorm mine the ledge is faulted down and its eastern continuation has not been found, so far as known. The so-called East Snowstorm and Pandora prospects are in higher beds south of the fault and no commercial ore was seen in them. Some prospects north of these were not visited.

SNOWSTORM MINE.

ECONOMIC FEATURES.

The Snowstorm mine is of especial interest because it is still the only producer of copper in the district, because of the uncommon character of its ore, and because it presents an important practical problem of geologic structure. It is for the last reason in particular that a reexamination has been desirable, for the great amount of development work done since 1904 has revealed structural details that were not then apparent.

The mine is situated in Daisy Gulch, which empties into the South Fork of Cœur d'Alene River, about 3 miles above Mullan. The present working adit is a tunnel 4,750 feet above sea level, near the entrance of which has been erected a large boarding house and several other buildings used in working the mine. The ore is transported by aerial tramway to Larson, at the mouth of the gulch, where there is a station on the Cœur d'Alene branch of the Northern Pacific Railway. Larson consists of buildings owned by the Snowstorm Mining & Milling Co., including the mill and the principal office. In the fall of 1912 about 100 men were employed at the mine and about 50 at the mill.

Information supplied by the company concerning the production of the mine in recent years is given in the table below. Each yearly interval begins on July 1.

Production of Snowstorm mine, 1906–1912.

Year.	Total.	Copper.	Silver.	Total value.
	Tons.	*Pounds.*	*Ounces.*	
1906–7	76,224			
1907–8	87,503			
1908–9	119,816	10,363,438	734,968	$1,292,872
1909–10	91,368	7,125,105	605,075	922,686
1910–11	34,464	2,653,036	267,263	350,064
1911–12 Crude	29,964	2,029,474	202,583	323,639
1911–12 Concentrates	130.67	44,973	2,287	7,307

The low production of 1910–11 and later is explained by the fact that most of the company's efforts in this period have been devoted to exploration and development work. The gross production of the mine to December 1, 1911, was $8,944,000.

The ore of the Snowstorm mine consists of small particles of copper minerals disseminated in quartzite. That which was being mined at the time of the former examination, in 1904, was for the most part oxidized and consisted largely of carbonate. A leaching plant that was being constructed in that year for the treatment of the ore was operated successfully for several years. It was found, however, that the sulphide ore, which preponderated in depth, could not be treated economically by a leaching process, and the leaching plant has been replaced by a concentrator whose present capacity is about 100 tons a day. Much of the ore is still shipped crude, the separation of crude ore from milling ore being effected partly in the mine by "shovel sorting" and partly by hand sorting. The proportion shipped crude varies according to the demand for siliceous ore of this kind.

The tenor of the crude ore in copper is about 3.5 per cent. Owing to its high proportion of silica—about 90 per cent—it finds no steady market, but is sold in small lots to smelters that need silica. The fact that the use of siliceous converter linings is decreasing makes the ore more difficult to dispose of than formerly.

The concentrating ore contains about 2.75 per cent of copper and is concentrated to a product that contains 20 to 25 per cent. The concentrates are all sent to the Tacoma smelter.

The ore is concentrated by ordinary wet gravitational processes. The chief difficulty arises from the minute division of the ore minerals, which necessitates very fine grinding. The saving was not much better than 50 per cent at the time of visit, but has since been increased by the installation of certain improvements.

It appears from the figures of production that the ore yields on an average about 2 ounces of silver for each 20 pounds (that is, for each "per cent") of copper, but that the silver is more liable than the copper to loss in concentration, the silver ratio in the concentrates being about half as great as in the average ore.

THE ORE.

The principal unoxidized ore of the Snowstorm mine consists of quartzite impregnated with minute particles of bornite, chalcocite, and chalcopyrite. The richest ore appears of a uniform dark-gray tone; the leaner ore is lighter and finely dappled or speckled. A relatively small proportion of the copper ore occurs in veins and bunches associated with quartz, these being especially abundant in the eastern part of the mine. Tetrahedrite is said to be a constituent and is the probable source of the silver. Although the greater part of the ore now in sight is of the disseminated sulphide variety, the oxidized ore, which was the chief product in early years, is still being mined. In this the sulphides have been converted chiefly to malachite but partly to cuprite. The carbonate ore is greenish brown, being stained by limonite. The most thoroughly decomposed ore is soft and of a bright-red color that suggests a high content of cuprite, but this material is said to be in reality very poor in copper, and the color is therefore probably due in the main to iron oxide. Malachite with some azurite forms thin films on joint faces. The walls of some drifts on the No. 3 tunnel level are gorgeously colored with these carbonates, although the ore here is lean. Some oxidation has occurred as far down as No. 4 tunnel, more than 1,600 feet below the outcrop, but the carbonate ore is not abundant below the 600-foot level.

UNDERGROUND WORKINGS.

The Snowstorm ledge is tapped by four tunnels. The No. 1 tunnel is disused; No. 2 is blocked but connected with the surface by an air shaft; No. 3 is the working adit; and the No. 4 level is the one on which most of the exploration has been done in recent years, although much ground has also been explored on the No. 3 tunnel level. Drifts have been run on the 100-foot (tunnel No. 1), 400-foot (tunnel No. 2), 600-foot, 700-foot, 800-foot, 900-foot, 1,000-foot, and 1,100-foot (tunnel No. 3) levels. Tunnel No. 4 is 535 feet below tunnel No. 3 and therefore about 1,600 feet below the outcrop.

GEOLOGIC CONDITIONS.

The workable ore of the Snowstorm mine occurs for the most part in a stratum of Revett quartzite, about 40 feet thick, which may conveniently be referred to by the term in use at the mine—"the ledge." This ore-bearing stratum is distinguished lithologically from the rock immediately above and below by its harder and grittier character. The quartzite of the ledge is thick bedded and medium grained and contains very little sericite; the portion not colored by the copper minerals is almost pure white. The rock immediately above and below the ledge is more flaggy, finer grained, softer, and more greenish, the last two characteristics being due chiefly to the presence of sericite in considerable quantity. The lower limit of the ledge is the more sharply defined. It is marked by an abrupt change in the character of the rock and in most places by a slip, which, however, appears to be no more significant than the innumerable bedding-plane slips found everywhere in this region at the contact of soft beds with hard and which in few places contains more than an inch of gouge. The country rock below this "footwall" contains a little ore in places, but on the whole the coincidence of the contact between hard and soft quartzite with that between commercial ore and the practically barren underlying rock is remarkably close. The upper limit of the ledge is less definite with respect to both lithologic character and tenor, and in working westward successive beds on the hanging wall have been abandoned as too poor to work.

The reason for the remarkably definite limitation of the ore to a comparatively thin stratum of quartzite is far from clear. A partial explanation is indeed suggested by the behavior of the mine waters, which evidently circulate with much greater freedom in the harder and purer quartzite than in the softer and more sericitic rock. It is natural to infer from this that the ore-bearing solutions flowed through the purer quartzite, which became impregnated by them because of its relatively porous texture. But this conclusion does not explain the fact that a great part of the quartzite penetrated by the mine workings, though apparently identical in character with the matrix of the copper minerals, is nevertheless quite barren.

The bedding of the Revett quartzite in the mine and consequently the ledge itself dip steeply south-southwest. A few hundred feet south of the ledge, on the surface near the workings, is a reversed fault whose general strike is east and west and which has a steep dip to the north. The relations are such that in depth the ledge is cut by the fault, and the segment south of the fault is relatively depressed.

These structural features were stated and illustrated diagrammatically by Ransome[1] in the report that was based on the exami-

[1] Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 150.

nation made in 1904. Chiefly on the basis of the geologic mapping, which was done by F. C. Calkins, the fault was said to be between Revett and St. Regis beds; its throw was estimated as not less than 700 feet, and its dip was shown as being such that the ore-bearing stratum would probably be cut off about 100 feet below the level of tunnel No. 3.

It now appears, from facts of which some were overlooked and others inaccessible to observation in 1904, that this description of the structure, though true in essence, is incomplete and open to some quantitative correction. The extensive workings on the No. 4 tunnel level, which had not been begun in 1904, show that the structure is more complex than was supposed and that the movements ascribed to a single fault should rather have been ascribed to a fault zone, of which the fault that was recognized was the northernmost member. The throw of this particular fault is probably less than 700 feet, for the rock on the south side of it in the mine belongs chiefly to the upper part of the Revett quartzite rather than to the St. Regis, and the ledge has been found on the No. 4 tunnel level in a position which it could not occupy if the quantitative elements of the former interpretation had been correct.

The recent reexamination made this much apparent; but it was not complete, inasmuch as the weather prevented a review of the surface exposures, and therefore an attempt to interpret the structure in detail would still be premature. Even the downward course and the throw of the northernmost fault are still somewhat problematical. The structural facts of chief practical importance, however, are fairly clear from the exposures on the No. 4 tunnel level. Two segments of the ledge appear on this level, cut apart by an east-west fault, which may be the northernmost main one; but if so, the general dip of this fault, which averages about 70° above No. 3 tunnel, must become vertical below that level. Another considerable fault, which brings St. Regis beds against Revett, is about 500 feet south of the one just mentioned in the eastern part of No. 4 tunnel level. Westward it converges slightly toward the other. Between these two faults are others that strike more nearly north and south, but the ledge is sufficiently exposed to show that a large part of it south of the main Snowstorm fault is unaffected by important fractures and could readily be opened.

The ledge, however, is not all composed of commercial ore. The portion rich enough to work at a profit—the ore shoot—has a maximum stope length of about 700 feet. It has a pitch of about 90° near the surface, but this quickly changes to a low eastward pitch. As the strike of the bedding and main fault converge toward the east, it follows that the ore shoot is cut off at less depth than the ledge, and practically no commercial ore has been found below the 900-foot level. The portion of the ore shoot south of the main fault, if the shoot persists across that fracture, is presumably below the level of tunnel No. 4.

The element of uncertainty implied in the last sentence is one that should be frankly considered. Although the structural relations prove that the ledge is older than the faulting, it seems possible and has indeed been suggested that the concentration which produced commercial ore is later than the fault, and that the ore forming the shoot was deposited by downward-moving waters, which were dammed by the fault gouge. If this were true, the ore shoot, which has thus far proved productive, would not continue beneath the fault. Some plausibility is given to this hypothesis by the freedom with which water circulates in the crevices of the brittle quartzite of the ledge and the relative impermeability of the thicker fault gouges. The drifts on the No. 4 tunnel level in the quartzites north of the faults—that is, above them—are comparable to a vast cold shower bath. The tunnel south of the faults is relatively free from water, and some of the points at which the drifts cross wide gouges are the driest places in the mine. The gouges undoubtedly act as dams, and concentration might conceivably be due to the retarding effect of the gouge upon the mineralizing solutions. If this were true, however, evidence of the fact should be presented by the distribution of the ore. It might reasonably be expected, in such a case, that the ore shoot would extend along the intersection of the fault with the ledge. As a matter of fact, no such relation between the ore shoot and the fault is apparent. The only modification of the ore that seems to be related to the faulting is the occurrence of copper veins in the eastern part of the workings. This occurrence, however, is probably due to reconcentration of the ore in fissures contemporaneous with the major faults, and the disseminated ore of the pay shoot was evidently formed in a different way. It therefore seems reasonable to hope that a continuation of the pay shoot may be found below the No. 4 tunnel level.

SNOWSHOE PROSPECT.

The Snowshoe property is near the head of Gentle Annie Gulch, about half a mile west of the Snowstorm mine and but a short distance east of the Lucky Calumet. The workings consist of a tunnel 1,400 feet long, driven N. 60° E., near the end of which a drift runs for about 400 feet in an irregular course, averaging S. 70° E. The first 400 feet of the tunnel is driven in fine-grained green quartzites and shales, in which are a few dark-colored bands. This formation gives way to purple shales and quartzites, undoubtedly St. Regis, which continue to the Snowstorm fault, 150 feet from the drift. Beyond the fault the thick-bedded white Revett quartzite occurs. Numerous faults or slips, most of them accompanied by gouge, were noted in the tunnel section. They are, in the main, conformable to the bedding planes, but some cross at small angles. The Snowstorm fault is accompanied by brecciation and gouge.

The ore consists of pyrite, chalcopyrite, chalcocite, etc., sparsely disseminated in the thick-bedded hard Revett quartzite exposed in the drift, the mineralization being the same as in the ores of the Snowstorm mine, but leaner. This zone has been proved for the length of the drift, and its width is from 30 to 40 feet as measured along the tunnel section, but the beds dip about 60° S., making a correction necessary.

LUCKY CALUMET.

The Lucky Calumet property is situated near the head of Gentle Annie Gulch, about a mile west of the Snowstorm mine. The workings consist of a tunnel about 1,700 feet long, driven N. 50° E., and drift about 300 feet long, driven N. 40° W., from a point 100 feet from the breast of this tunnel. The southeasterly extension of the drift, from which comes a large flow of water, is bulkheaded.

From the entrance for a distance of 600 feet the tunnel is driven through purple shales and quartzites of the St. Regis formation, then for about 200 feet through green quartzites, and finally into the typical hard, massive white Revett quartzite. The strike of the formation is uniformly northwest, but both north and south dips, due to folding and faulting, were noted in the outer half of the tunnel. About 800 feet from the tunnel entrance a brecciated zone and loose ground, requiring lagging, suggest a considerable fault, probably the westward extension of the Snowstorm fault.

Little evidence of mineralization was noted in this tunnel. Evidently the exploratory work is done in the hope of striking the supposed continuation of the Snowstorm ore body. In the drift rust specks were noted in the massive quartzite, but none of the disseminated copper sulphides characteristic of the Snowstorm deposit. Assessment work at the time of visit was much impeded by the heavy flow of water in the quartzite.

MISSOULA COPPER.

The Missoula copper property is at the head of Deadman Gulch, about 1½ miles northwest of the Snowstorm mine. The workings consist of a tunnel and drifts aggregating 4,500 feet in length, with a connecting shaft on one of the drifts. The shaft is probably several hundred feet in depth. The main tunnel trends N. 30° E. for 1,900 feet and about N. 70° E. for 700 feet. From this tunnel several drifts follow quartz veins or slip planes. The entrance of the tunnel is in the purple shales of the St. Regis formation, but these soon give way to greenish thin-bedded quartzites of the upper part of the Revett quartzite, and the green quartzites in turn are underlain by the typical thick-bedded hard white Revett quartzite. The strike is in general northwesterly, with dip to the south, but as the distance from the tunnel entrance is increased the strike gradually swings more to the north. At the entrance of the main tunnel the strike is about N. 55° W., but at the breast the strike is N. 20° W. Numerous faults and minor slips occur in the bedding planes and a smaller number cross the strata. These disturbances were usually accompanied by the formation of quartz veins.

The ore consists of a mineralized quartz vein and disseminated sulphides, which are exposed in a drift 1,250 feet from the entrance on the tunnel level. The drift runs northwesterly and follows a quartz vein, which varies from a few inches to 2 feet in width. About 500 feet from the entrance to this drift a shaft and near by a raise are located. The shaft and raise were not examined. The vein contains scattered bunches of galena and chalcopyrite and is richest in the vicinity of the shaft, but nowhere does it give indications in itself of being a commercial deposit. A peculiar feature of mineralization attendant on the rich part of the quartz vein is the occurrence of finely disseminated sulphides in the hard quartzites on either side of the vein. This type of ore is very similar in appearance to the leaner ores of the Snowstorm mine. In the drift 75 feet northwest of the shaft these disseminated sulphides extend only a foot or two on either side of the vein, but in a drift which extends south from the shaft this type of mineralization extends for a distance of 30 feet. The dip of the quartzite here is about 30° S. About 150 feet southeast of the shaft no disseminated sulphides were noted and the quartz vein is apparently barren. At a point about 550 feet from the tunnel entrance finely disseminated copper and iron sulphides were noted in the hard quartzites, but their occurrence at this point is both sparse and of very small extent.

UNITED COPPER MINE.

The United Copper property is in Deadman Gulch, the entrance to the main adit, known as the National tunnel, being near and between the main forks. The examination of this mine consisted of a single hasty visit in which only the lowest level was examined. Mr. George Huston has obligingly supplied considerable information regarding progress since this visit and has sent good specimens of representative ore. This description, however, must still be inadequate to the prospective importance of the property.

The National tunnel is about 4,300 feet long and its direction is a little east of north. At the time of visit the only other work on this level consisted of a short drift to the east, a few hundred feet from the face of the main tunnel. Since that time considerable more work has been done, development having been stimulated by a strike of what promises to be commercial ore.

The prevailing dip of the country rock is southwestward, and in going northward into the tunnel one encounters successively the Newland, St. Regis, and Revett formations. These are broken by numerous fissures, along some of which considerable faulting has taken place. A short distance south of the drift the tunnel is crossed by a zone of brecciation marking, in the opinion of Mr. Huston, a fault between the Revett and St. Regis formations, with downthrow on the south and strike approximating east and west.

The drift, at the time of visit, was being driven along a fissure zone in which there was some quartz containing small amounts of chalcopyrite and chalcocite. These minerals were also disseminated in the country rock, but in a manner somewhat differing from that characteristic of the Snowstorm ledge; the particles were comparatively large but rather sporadic in distribution and not abundant enough to constitute commercial ore. Shortly after this time a vein of chalcopyrite several inches thick was encountered, and somewhat later the drift penetrated the ore on whose development the future of the property is likely to depend. This ore is essentially similar to that of the Snowstorm mine and consists of a stratum of quartzite speckled with minute particles of chalcopyrite and richer sulphides. The tenor is less than that of the best Snowstorm ore and probably does not run more than 3 per cent of copper, together with 3 ounces of silver and a negligible quantity of gold. The proportion of chalcopyrite is larger than in the Snowstorm mine, where enrichment has apparently been more extensive. The United Copper ore shows clear evidence of replacement of chalcopyrite by chalcocite, as was pointed out by Mr. Huston. The ore body is about 50 feet thick and has been shown to be at least 350 feet long. As its strike is northwest and its dip south, it must converge toward the east with the fault mentioned above. As the dip of this fault is southward, however, the ore can probably be followed downward to a considerable depth.

COPPER KING MINE.

The Copper King property is on the West Fork of Deadman Gulch, northwest of the United Copper. The principal development is on the lowest level, which alone was hastily examined. The main tunnel is about 5,000 feet long and drifts and other crosscuts aggregate several thousand feet in addition.

As in the National tunnel, the prevailing dip is southwestward, although there has been some folding and faulting. The rocks in the outer part of the tunnel belong to the Newland formation, which is succeeded on the north by the St. Regis; the Revett quartzite has not been penetrated.

The principal ore body observed is a vein striking about west-northwest and dipping 40° S. Its average thickness is only about 1 foot. It contains galena, sphalerite, chalcopyrite, and pyrite in a gangue consisting chiefly of quartz and calcite. The wall rocks are slightly mineralized. The size of the lode, however, is apparently not sufficient in the workings seen to permit profitable extraction. There seems to be some difficulty in finding the vein east of the main tunnel. According to Mr. Huston considerable work was done subsequent to our visit on an ore body south of that mentioned. This consisted of a band of country rock strongly impregnated with chalcopyrite and galena. This ore would be difficult to concentrate economically. Its thickness is about 2 feet. At last accounts this ore body had been found to be cut off by a fault and had not been found on the other side of it.

THE LEAD-SILVER DEPOSITS OF THE DOME DISTRICT, IDAHO.

By Joseph B. Umpleby.

SITUATION AND HISTORY.

The Dome mining district, situated in the northeast corner of Blaine County, Idaho, consists of the southern part of the area known in the early history of the region as the Hamilton mining district. It is reached by triweekly stage from Arco, a station on the Mackay branch of the Oregon Short Line Railroad, about 50 miles distant by the road commonly traveled. This road leads down the valley of Little Lost River to the Snake River Plains and thence along the margin of the plains to Arco, situated near the mouth of the valley of Big Lost River. A route 15 miles shorter, but with a grade too steep for heavy traffic, leads across the range of mountains that separates the valleys of Big and Little Lost rivers.

Lead-silver ores were discovered in the district about 1880, and during the following decade most of the deposits now recognized were worked. At that time the ore was hauled 75 miles to a smelter at Nicholia, near the head of Birch Creek. Only high-grade ores could be handled, and from these possibly $75,000 was produced, mostly from the Great Western group of claims, which has been idle for many years.

The chief interest in the district at present centers in the Wilbert mine, formerly the Daisy Black. This property was located many years ago, but made its first production about 1906, when two hand jigs were installed and a few tons of concentrates were shipped. In the fall of 1911 H. S. Knight, A. S. Ross, and associates, of Salt Lake City, purchased the property, organized the Wilbert Mining Co. (Ltd.), and built a 100-ton concentrating mill which made its first run in May, 1912. By July 20, 1912, the date of the writer's examination, the mill had handled about 2,400 tons of ore and produced 300 tons of concentrates which carried 51 to 53 per cent of lead and about 9 ounces of silver to the ton. The saving during this run was a little less than 70 per cent, or about 10 per cent below that estimated for the mill. By the end of the year the mill had produced concentrates which yielded approximately 1,500,000 pounds of lead and 10,000 ounces of silver.

FIELD WORK AND ACKNOWLEDGMENTS.

This paper records the more important observations made during a visit of four days in July, 1912. The work was part of an extensive reconnaissance in southeastern Idaho north of Snake River, and a fuller account of the deposits of the district will appear in the general report.

The field work was greatly facilitated by the underground maps and general information courteously supplied by Mr. H. S. Knight, general manager of the Wilbert Mining Co., and to him the writer desires to express his appreciation. Thanks are also due to Mr.

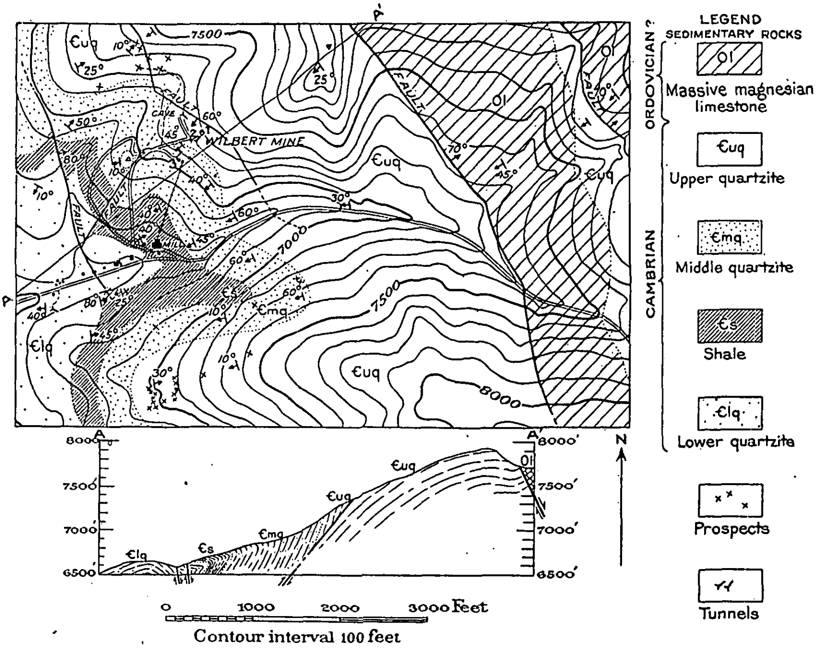


FIGURE 21.—Reconnaissance map and section of the central part of the Dome mining district, Idaho.

Charles A. Peet for supplying points of topographic control. Mr. C. H. Gray, assistant throughout the general reconnaissance, helped in the construction of the map shown as figure 21.

TOPOGRAPHY.

The district comprises a segment of the western slope of the high range which separates the valley of Little Lost River from that of Birch Creek. From the margin of the broad basin in which Little Lost River flows the slopes rise abruptly to elevations of more than 10,000 feet in the eastern portion of the district. In the northern portion Pass Creek, a tributary of Little Lost River, has cut a deep canyon far into the mountains and is the only stream readily available for local development of power. A canyon of comparable size, but containing only an intermittent stream, extends eastward in the central portion of the district. This canyon is shown on figure 2. About a mile farther south is still another large canyon, in which is situated the Great Western group of claims.

GEOLOGY.

FORMATIONS.

The rock formations exposed in the district are made up predominantly of quartzite, but interbedded with the quartzites is a distinct shale member, and above them are massive beds of magnesian limestone. So far as known the workable ore deposits occur wholly within the quartzite areas. Three distinct quartzite formations are indicated on the map, and for convenience in reference they will be designated as upper, middle, and lower. It is probable that, had time permitted, the upper quartzite could have been subdivided into at least three parts.

The lower quartzite is the oldest formation exposed in the vicinity of the mines. It is a massive or semimassive white rock which has a wide range in texture, but in most places is pebbly, with subangular pebbles of quartz up to a quarter of an inch across, cemented by finer siliceous material. The total thickness of this formation is not known, although beds at least 200 feet thick are exposed in the north side of the canyon below the Wilbert mine.

A shale formation possibly 150 feet in thickness overlies the lower quartzite, though in some places the beds are overturned and the shale underlies the quartzite. This shale has been compressed, at least locally, until the bedding planes are in most places obscured by slaty cleavage and schistosity, which are the characteristic features of the formation. The rock is greenish gray in color and breaks readily into irregular plates which commonly have curved surfaces. Its metamorphism was accompanied by considerable recrystallization, giving rise predominantly to chlorite and sericite.

Above the shale formation is the middle quartzite, which, as measured in the canyon above the Wilbert mill, is 475 feet thick. This formation is readily recognized by its maroon color, which contrasts sharply with the prevalent light grays of the other quartzite formations. The lower part of it is made up of thick beds, some of which are intricately cross-bedded, but the upper layers are thin and regularly stratified.

Next younger is an assemblage of quartzites which are here mapped as the upper quartzite. These strata are at least 800 feet thick, although their full thickness is probably not exposed in the area studied. The lowest beds of this assemblage comprise 25 feet of milky-white fine-grained quartzite, overlain by 6 feet of dark-gray medium-grained quartzite, then 10 feet more of the milky-white variety, which grades into a brownish-gray facies containing numerous annelid borings, the total to this horizon representing a thickness of about 170 feet. This portion would be the lower division if the upper quartzite series were subdivided. Above the brownish-gray quartzite is 80 feet of thin-bedded clear-white fine-grained quartzite, which from local evidence might also be considered a distinct unit. This is overlain by 550 feet of massive quartzite beds of light-gray color and fine-grained texture.

Above the quartzite series are massive beds of magnesian limestone, which were not examined carefully, as they occur at a considerable distance from the known deposits of ore. These limestones are unquestionably several hundred feet thick and constitute the predominant rock near the center of the range east of Wilbert.

It is believed that the quartzites are of Cambrian age and the magnesian limestones are Ordovician, a belief based on relations noted elsewhere during the general reconnaissance rather than on local evidence.

STRUCTURE.

The dominant structural features in the central part of the district are a number of normal faults which strike about N. 30° W. and an overturned fold along which thrust faulting has taken place. The thrust fault (or faults) has about the same strike as the normal faults, but it dips southwest, while they dip northeast. Both types of displacement have thrown younger beds on the northeast against older beds on the southwest. It is thought that the two types of faults represent distinct epochs of disturbance, and that the folding and thrust faulting took place first.

The overturned fold may perhaps be studied most easily in the vicinity of the Wilbert mill. Here the shale is bounded on the west by the lower quartzite and on the east by the middle quartzite, rocks quite different in appearance. On the west the dip is easterly and on the east it is westerly. Exposures in the group of prospects along the road from the mill to the mine clearly show that the shale extends beneath the middle quartzite, and numerous exposures west of the mill indicate that the lower quartzite extends beneath the shale. The overturn has thus been from the southwest toward the northeast, as shown in the section on figure 21. The fault along the northeast side of this fold was not adequately studied, but seems to have a definite relation to the ore deposits. Indeed, some of the ore bodies exposed on the lowest level of the Wilbert mine appear to be along this fault. Northwest of the mine the fault may be traced with a fair degree of certainty well beyond the limits of the area mapped, but to the southeast it is not known to cross the canyon, although as there is generally little accompanying breccia it might readily be overlooked in this area of uniform rock.

The maximum displacement of this fault can not be more than a few hundred feet and may be less than 100 feet. The rocks in the footwall are not greatly disturbed, but those in the hanging wall are most intricately fractured, and it is in this fractured zone that the Wilbert ore bodies occur.

Four distinct normal faults of considerable extent are shown on the map. Two of these have dropped the magnesian limestone against the upper quartzite and the other two have appreciably offset the lower quartzite and shale contact. The age relation of these displacements to the folding and thrust faulting is shown clearly in the Wilbert mine, where the ore bodies, which formed along fractures related to the thrust faulting, have been offset by many normal faults of minor throw.

ORE DEPOSITS.

DISTRIBUTION AND DEVELOPMENT.

There are four local centers of prospecting and mining in the Dome district, but of these only the Wilbert group of claims has been actively exploited in recent years. About 2 miles north of the Wilbert mine is the Johnson property, where 300 feet of development work has been done on a number of small veins in magnesian limestone. The Great Western mine, 1½ miles south of the Wilbert, comprises about 2,000 feet of tunnels and is reported to have produced early in the history of the district $50,000 from silver-rich lead ores. It has not been worked for a number of years, and most of the workings are said to be inaccessible. About 3½ miles south of this mine are the South Creek properties, from which a few small shipments have been made. The Wilbert property consists of 13 claims, two of which are patented, and is developed by about 2,500 feet of tunnels, raises, and crosscuts. Only the Wilbert and Johnson deposits were examined.

CHARACTER.

The following description of the ores and their occurrence is based entirely on observations made in the immediate vicinity of the Wilbert mine. The ore here found occurs as veins, stringers, and disseminations in the fine-grained upper quartzite, most of the production coming from the disseminated lead-silver ores. The known ore bodies are very erratic in size and distribution, although they are all related to a general zone of fracturing and, except where offset by faults, are usually connected by stringers. The shoots commonly strike N. 20°–30° W. and dip either to the east or to the west at angles varying from 20° to 80°. The mine is opened on three levels, with upper and lower intermediates between the two lower tunnels, as shown in section by figure 22. The uppermost ore body crops out a short distance above tunnel No. 1 and extends downward on a dip of about 60° SW. to a point 10 feet below level No. 2, where it is cut off by a flat-lying, westward-dipping fault. All the ore bodies found between this fault and the lower intermediate level are flat-lying and of irregular shape, but in the main dip eastward. On the lowest level, No. 3, a fairly distinct fissure, along which are two ore shoots separated by 75 feet of comparatively barren ground, has been followed for 350 feet. The south shoot is 60 feet long and varies in width from a few inches to 2 feet. The north shoot has been explored for 180 feet. This shoot contains ore of excellent

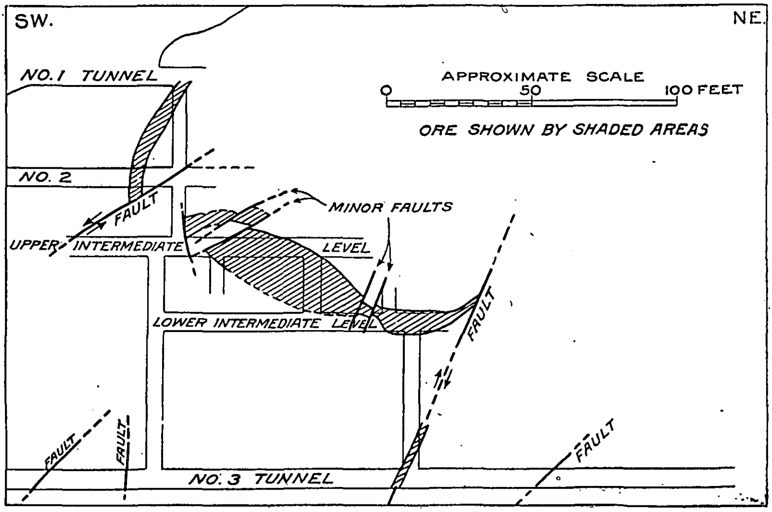


FIGURE 22.—Transverse section through the Wilbert ore bodies, Dome district, Idaho, along line of tunnel No. 3.

grade and occurs as a fairly distinct vein from a mere stringer to 3 feet in width, averaging perhaps 2 feet. Both shoots strike about N. 20° W. and dip 60° NE. The two shoots found on the third level probably extend to the lower intermediate level, 55 feet above, where two bodies of similar ore occur in normal relation to them. The south shoot presents a peculiar feature above the lower intermediate level, where it rises toward the north in the plane of the vein at an angle of about 20°. This portion of the shoot has been followed upward by an incline for 150 feet, and its average cross section so far as known is said to be about 7 feet by 6 to 20 feet. Both of these ore shoots are out of the plane of the transverse section, figure 22.

Another shoot of ore crops out near the portal of the Cave tunnel, but the development here has not been sufficient to define its attitude. The portal of the Cave tunnel is situated 300 feet N. 17° W.

of portal No. 2, at practically the same elevation. Just south of it a considerable tonnage of ore has been taken from an open cut in loose surface rock. The ore occurs as chunks from the size of a walnut to several feet across. Immediately beneath this open cut a short drift south from the Cave tunnel enters a flat-lying body of ore 3 feet thick which is inclosed in manganese-stained quartzite and averages about 25 per cent of lead. Its boundaries have not been defined.

RELATION OF THE ORE DEPOSITS TO GEOLOGIC STRUCTURE.

An adequate account of the deposits would involve the consideration of many structural problems, but the short time allotted to the work in this district made it impracticable to attempt even local detailed studies of structure. Certain broad relations, however, were worked out which should serve as primary control in the interpretation of local detailed observations. The Wilbert ore bodies occur along the zone of sharpest bending in an overturned anticline. The rocks here were greatly fractured during the development of the overturned fold, and in some places, perhaps in most places, the formations along the crest of the fold broke and a thrust fault resulted. In the small gulch north of the Wilbert mine a fault of this kind is clearly shown, and in the mine itself several small ones have been identified.

After the compressional stresses that caused the folding and the thrust faulting the area was subjected to tensional stresses, which gave rise to the normal faults indicated on the map.

The ores were deposited along fractures developed during the epoch of folding, and in many places were offset during the epoch of normal faulting. The form of the ore bodies is therefore determined by the extreme irregularity of the earlier fractures, and their position is determined both by these fractures and by subsequent faults. In many places the later faulting has found expression as small movements along the earlier fracture planes, thus causing a brecciation of the ore where no offset is seen.

THE ORES.

The ore of the Dome district is of especial interest, because in much of it the ore minerals occur as minute grains disseminated in quartzite. Ore of this variety has a "pepper and salt" appearance, but the relative amounts of the light and dark grains are very different in different places and locally within distances of a few inches. In most places the ore bodies of this type blend with the inclosing rock by imperceptible gradation through a zone from a few inches to 5 feet wide. Poorly defined bands of fairly pure galena cut in various directions through the irregular masses of disseminated ore and in places coalesce into rather distinct veins made up of thin lenses and stringers of galena and anglesite. In the Wilbert mine the disseminated ore is characteristic of the flat bodies between tunnels No. 2 and No. 3, and the thin lenses and stringers occur extensively in the shoots developed on the lower intermediate level. Still another ore type is represented in the north shoot opened on level No. 3. Here galena forms the cement in a quartzite breccia, which occurs along a fault zone. The quartzite of the breccia is in many places not mineralized, a fact that seems strange in view of the exceptional extent to which galena has been deposited in the wall rock of the upper levels.

The mineralogy of the ore is simple, galena and its oxidation products, anglesite and cerusite, being the only abundant minerals. The galena occurs as the dense variety commonly known as steel galena, and its oxidation products are similarly fine grained. A few crystals of calamine were seen on level No. 3, suggesting the presence of sphalerite as a primary mineral, and here also a few copper stains and a little linarite (hydrous copper-lead sulphate) suggest the presence of some copper sulphide. These minerals, however, are negligible in amount.

Thin sections of the ore studied with the microscope show that the galena of the disseminated ore replaced the cement and to some extent the quartzite grains in a fine-textured quartzite. Some of the unaltered quartzite has a lime-silica cement, but in those beds in which the ore occurs the cement seems to have been entirely siliceous. Specimens of the disseminated ore effervesce slightly in acid and show in thin section a small but rather evenly distributed amount of cerusite on the outer margins of anglesite areas, many of which contain cores of galena. This carbonate, the only one noted in the sections of ore studied, is clearly of secondary origin.

In the disseminated ore anglesite, the sulphate of lead, is by far the most abundant metalliferous mineral. Sections of it usually show irregular cores of the galena from which it was formed. The alteration of galena to anglesite necessitates a volume increase of approximately 52 per cent (computed on the basis of average specific gravities), and the change from galena to cerusite an increase of only 28 per cent. In these deposits anglesite occurs so commonly as a band between a core of galena and a rim of cerusite that it is probably safe to assume that here at least it is generally an intermediate stage in the alteration of lead sulphide to lead carbonate. The volume change in the alteration of any given grain of galena is therefore first a 52 per cent increase in volume and then a 24 per cent decrease, the net result when carbonation is complete being a 28 per cent increase. The maximum possible increase of 52 per cent is probably never realized, for it is likely that cerusite begins to form before a given grain of galena is completely changed to anglesite. There is, however, a cycle of volume change in the direction stated. The writer believes that this increase in volume followed by a marked decrease during alteration accounts for the "sand carbonate" ores of many mines, so named because of the loose assemblage of the cerusite grains. In this deposit the volume changes which accompany the alteration of galena to anglesite and of this in part to cerusite appear to have had a decided influence on the coherency of the inclosing rock and to account for the loose, sandy condition of the plumbiferous quartzite, as opposed to its firmness and close texture where not metalized.

The ores found in the Wilbert mine are very different in tenor, the disseminated ore containing from 12 to 20 per cent of lead and the vein ore, made up of lenticular masses and stringers, from 20 to 30 per cent of lead. During the month of December, 1912, when the mill handled 50 tons a day, the average tenor of the ore was 23 per cent—somewhat higher than that for previous months. Recent developments, however, have encouraged the management in the hope to keep a mill feed of 20 to 23 per cent of lead. Ore of this grade usually contains about 3½ ounces of silver to the ton.

ALTERATION OF THE WALL ROCK.

A conspicuous and noteworthy feature of these deposits consists in the abundant oxides of iron and manganese which characterize the wall rock for several feet away from the ore bodies. These oxides are most abundant next to the ore and where observed grade out to unaltered quartzite within a distance of 10 to 50 feet. The altered wall rock is striking in appearance, a bright yellow groundmass of iron oxide being studded thickly with small specks of dendritic manganese. The oxides occur not only along the innumerable fracture surfaces, but throughout the rock as interstitial fillings between the quartz grains. Calcite generally accompanies the metallic oxides. Perhaps its most common situation is along the cleavage cracks, but in places it occurs also interstitially between the quartz grains. In many parts of the hand specimens where no carbonate is visible, even with the aid of a hand lens, a drop of acid causes vigorous effervescence, indicating that the calcite is present but is concealed by the oxides.

The occurrence of these oxides and calcite in the wall rock is in every particular comparable to the occurrence of the lead minerals in the disseminated ore. Both seem to have replaced a siliceous cement in the quartzite. This analogy, together with the definite decrease in their amount with increasing distance from the ore bodies and the ill-defined boundary between such rock and the bodies of disseminated ore, points rather conclusively to the development of some manganese-iron-carbonate mineral or minerals in the wall rock as an accompaniment of the primary mineralization. It is believed that these manganese and iron oxides must be regarded as a product of metasomatic alteration closely comparable to the well-known development of calcite adjacent to fissure veins.

The primary metasomatic mineral or minerals from which the oxides of iron and manganese and possibly also the calcite have been formed were not observed in any of the specimens. By inference, however, it seems probable that the primary metasomatic mineral was manganiferous iron carbonate. Siderite, a mineral which commonly contains manganese, is abundant in the gangue of many of the lead-silver deposits of Idaho and in the Cœur d'Alene district[1] it has been shown to replace quartzite to an important extent.

GROUND-WATER LEVEL.

The level of ground water is well below the present lowest mine workings. The bottom of the canyon at the Wilbert mill is approximately 400 feet below the lowest level of the Wilbert mine and only 1,000 feet away along the strike of the steeply dipping quartzite beds. The canyon at the mill is dry throughout most of the year, the stream which rises near its head sinking about 2 miles above the camp. Thus in the vicinity of the mines the elevation of ground-water level, though not susceptible of close determination from surface observations, is at least below the level of the bottom of the canyon at Wilbert.

SUMMARY AND PRACTICAL CONCLUSIONS.

The principal points of interest in this preliminary paper and the practical conclusions which may be drawn from it are as follows:

1. The Wilbert deposits contain important bodies of plumbiferous quartzite, a type of lead ore which, so far as the writer is aware, has not been previously described.

2. The mineralizing solutions caused noteworthy metasomatic alteration of the quartzite for 10 to 50 feet or more from the ore bodies, replacing the cement of the quartzite with some mineral (or minerals) which on breaking down gave limonite and pyrolusite and possibly also calcite.

3. The loose, sandy condition of the disseminated ore is thought to be due to the volume changes which accompany the alteration of of galena to cerusite, with anglesite as an intermediate stage.

4. The Wilbert ore bodies were formed after the folding of the rocks of the district but before they were displaced by normal faults. They present many structural problems which it is believed should be considered in the light of these two epochs of disturbance—one older than the deposits and the other younger—particularly

[1] Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 95, 97.

because many of the later movements have taken place along the old fracture planes, which in a large part determined the sites of ore deposition.

5. Manganese oxide in this district appears to be invariably present in the wall rock adjacent to the lead-silver ores, and hence may be considered an encouraging indication, both in prospecting and in mining. This statement, however, can not be taken to mean that manganese is everywhere accompanied by lead ore, but rather that lead ore appears to be everywhere accompanied by manganese.

6. The elevation of ground-water level in the district is not known definitely; but in the area of which figure 21 is a map it is certainly below the level of the bottom of the gulch, or at least 400 feet below tunnel No. 3 of the Wilbert mine.

THE YELLOW PINE MINING DISTRICT, CLARK COUNTY, NEVADA.

By James M. Hill.

INTRODUCTION.

FIELD WORK.

During the summer of 1912 the writer was detailed to visit a number of widely separated mining districts in Nevada and northeastern California. The work was entirely of a reconnaissance nature, and the results are far from complete. The last nine days of September were spent in the Yellow Pine district, Nevada's new and largest zinc camp. This report is based on a hasty inspection of most of the mines in an area of approximately 384 square miles.

The writer was fortunate in obtaining the services of Mr. Richard Feaster, whose acquaintance with the mines, roads, water holes, and people of the district did much to expedite the work. The mining men of the district extended many courtesies. Their open hospitality was much appreciated, and their interest in the work was such that all of them gave generously of their time and information. Particular thanks are due to Messrs. Fred A. Hale, C. D. Coates, George A. Fayle, John Frederickson, and Harvey Hardy.

In the preparation of this report the writer received assistance from a number of his colleagues in the Geological Survey and wishes here to express his thanks to them, particularly to Messrs. W. T. Schaller, E. S. Larsen, and J. B. Umpleby for mineralogic and petrologic determinations, to Mr. George H. Girty for the determination of the fossils, and to Messrs. Adolph Knopf and C. E. Siebenthal for criticism.

LOCATION AND ACCESSIBILITY.

The Yellow Pine mining district, sometimes called the Good Springs district, is in the southwestern part of Clark County, Nev., near the California line. It covers the southern part of the Spring Mountain Range. The mines lie on both sides of the ridge over an area 24 miles north and south by 16 miles east and west. This region is in the northern part of the Ivanpah and the southern part of the

Las Vegas quadrangles as mapped by the United States Geological Survey. (See Pl. IV.) The center of the district is 35 miles southwest of Las Vegas, the supply point for the greater part of southern Nevada.

The San Pedro, Los Angeles & Salt Lake Railroad, commonly called the Clark road, runs along the east side of the district, affording excellent transportation facilities for the mines on that side of the mountains. Jean is the principal shipping point, though the Potosi mine hauls its ore to Arden and some of the ore from the mines at the south end of the district goes to Roach. Good Springs, the principal town in this region, about 8 miles northwest of Jean, is now connected with the main line by the narrow-gage "ore road" belonging to the Yellow Pine Mining Co. It has a population of about 200 persons.

The settlement of Sandy (Ripley post office) is practically abandoned. It was built about the cyanide mill of the Keystone mine. At the Potosi live about 30 miners and nearly as many teamsters and laborers connected with the property. There are numerous small camps in all parts of the district, and visitors are always welcome at any of them.

The roads in this region are very good, considering the rugged character of the topography. The main routes of travel are: The road from Arden to the Potosi mine, the main road from Jean to Good Springs and Sandy, the road southeast from Sandy through State Line Pass to Roach, and the road north from Good Springs that connects with the Arden road southwest of Cottonwood Springs.

WATER SUPPLY.

The Yellow Pine district is more favorably situated for water than some of the mining camps on the desert. In both the Mesquite Valley, to the west, and the Ivanpah Valley, southeast of the mountains, a practically limitless supply of water can be obtained from wells 10 to 50 feet deep. The water in the Mesquite Valley is so close to the surface that several people have started dry farms.

In the mountains water is scarce. The only springs are shown on Plate IV. At Good Springs all the water, which is of excellent quality, is pumped. Potosi Spring yields plenty of good water for domestic use, but it is doubtful if there is sufficient to supply a concentrating mill using wet methods.

Most of the camps are without natural water supply and nearly all the drinking water used in the district is hauled from Good Springs or the Potosi Spring. The water from the wells at Sandy is strongly mineralized and not fit for drinking.

CLIMATE AND VEGETATION.

The Yellow Pine district is on the desert and its climate is typical of the dry region. The winters are relatively cool, and on some days the temperature approaches the zero mark. From May to October there are some very hot days, but the average temperature is not oppressive. Most of the precipitation falls as rain in the summer, though in the winter there is sometimes a light fall of snow, which does not last long. The prevailing winds are from the southwest. The daily range of temperature varies from 20° to 58° F., being perhaps a little more marked in the late spring and summer.

The vegetation is scant except on the slopes of Potosi Mountain above an elevation of 5,500 feet. Below this level sagebrush, greasewood, and several varieties of cactus are all that is seen. The wood of the so-called Joshua tree, a species of yucca, is extensively used for domestic fuel at Good Springs.

North of the district, in the vicinity of Charleston Peak, there was at one time a heavy stand of yellow pine, but lumbering operations have greatly depleted it. Some few pines grow near the summit of Potosi Mountain, with juniper and cedar.

At Wilson's ranch an irrigated tract produces good crops of alfalfa and fruits, and at Good Springs a few fruit trees are kept alive by careful watering. Apples, pears, peaches, and figs are the principal fruits grown. The Mesquite Valley farms were largely abandoned in the fall of 1912, owing, it is reported, to the difficulty of irrigating. The soil is so loose, porous, and dry that ordinary ditches will not carry the water for any great distance.

HISTORY OF MINING AND PRESENT CONDITIONS.

The first mining in this district of which there is any record was done by the Mormons about 1860 at the Potosi mine, which is called by some the Old Mormon mine. Lead ores were mined and smelted here to be later cast into bullets for use in the Mormon wars against the Indians or the United States troops. The mine is located on the west side of Potosi (Olcott) Mountain, just south of the old Salt Lake and San Bernardino trail, remnants of which are still to be seen in the gulch northeast of Potosi Mountain. The discovery of this mine led to prospecting which resulted in the opening of several lead-silver deposits, a few copper prospects, and at least one gold mine, the Keystone, which is reported to have produced about $1,000,000.

From the time of the earliest discoveries to 1906 the Yellow Pine district was a small though rather steady producer of lead, silver, gold, and copper. For a number of years a heavy gray-white material accompanying the lead ores was considered country rock and was thrown on the dumps. In 1906 Connie Brown, an engineer from Socorro, N. Mex., made a professional visit to Good Springs and recognized this material as similar to some of the zinc ores mined at Magdalena, N. Mex. Trial shipments of the zinc ore were sent to the Missouri zinc smelters, but the shippers were disappointed in their returns. Prospecting was continued, however, and mixed zinc-lead oxidized ores were found at many places.

The Yellow Pine mine was the first producer of good grade zinc ore, and after much experimentation the company has finally evolved a process whereby it is possible to separate the lead and zinc of the medium-grade ores into readily marketable products.

At the present time there are about 300 miners in the Yellow Pine district. The only companies operating their own mines in September, 1912, were the Yellow Pine, Ninety-nine, and Potosi. Most of the work is done by lessees on small scattered deposits. The production from this source is considerable.

PRODUCTION.

Records of production of the Yellow Pine district prior to 1902 are very incomplete. Since 1902 the United States Geological Survey has reported the production of the several States by mining districts, but the figures prior to 1906 are not particularly reliable. The subjoined table of production of the Yellow Pine district is taken from the volumes of Mineral Resources published by the Survey.

Production of Yellow Pine district, Nevada.

Year.	Gold.	Silver (fine ounces).	Copper (pounds).	Lead (pounds).	Zinc (pounds).	Total value.
1902	$44,174					$44,174
1903	53,396	753	21,800	28,000		55,665
1904	47,878	146				47,961
1905	15,000	3,707		290,063	685,659	71,335
1906	9,150	1,573	67,341	625,175	2,885,246	234,550
1907	9,743	2,994	93,090	187,310	1,879,432	151,156
1908	7,791	10,247	42,144	720,285	1,115,851	101,482
1909	5,740	18,461	392	406,353	3,013,352	195,585
1910	1,219	16,826	122,925	1,263,837	2,707,071	227,707
1911	2,424	47,072	173,719	1,617,224	3,548,032	324,100
	196,515	101,779	521,411	5,138,247	15,834,643	1,453,715

The decrease in the gold production since 1905 is due in large part to the closing of the Keystone mine. There is no record of the production of zinc prior to 1905; in fact, the shippers of lead-silver ores did not know of the presence of this metal and were probably penalized to some extent for such zinc as was shipped with the lead. Up to 1911 the zinc produced was derived entirely from crude sorted ore. In the latter part of 1911 the Yellow Pine Mining Co. started the operation of an 80-ton separating mill, which materially added to the production of the district, as it was then possible to mine in that company's property the mixed zinc-lead ores which were avoided as much as possible at other places.

PREVIOUS DESCRIPTIONS.

The literature bearing on the geology and ore deposits of the Yellow Pine district is very meager. The following list comprises practically all that has been published on the region:

Owen, J. R. N., Manuscript notes to the California Boundary Commission, 1861, Geol. Survey California, vol. 1, Geology, 1865, p. 471.

Raymond, R. W., Mining statistics west of the Rocky Mountains, 1871, p. 168.

U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 124, 166, 179, 180.

Spurr, J. E., Origin and structure of the Basin Ranges: Bull. Geol. Soc. America, vol. 12, 1901, pp. 235–236.

—— Geology of Nevada south of the fortieth parallel: Bull. U. S. Geol. Survey No. 208, 1903, pp. 164–180.

Bain, H. F., A Nevada zinc deposit: Bull. U. S. Geol. Survey No. 285, 1906, pp. 166–169.

White, Douglas, Zinc mines of southern Nevada: Proc. Am. Mining Congress, Goldfield, Nev., 1909, pp. 401–411.

Gregory, N. B., Yellow Pine district, Nev.: Eng. and Min. Jour., vol. 90, Dec. 31, 1910, pp. 1308–1309.

Hillen, A. G., Zinc in Nevada: Los Angeles Min. Rev., Sept. 24, 1910, p. 72.

Hale, F. A., Yellow Pine district, Nev.: Eng. and Min. Jour., Apr. 22, 1911, p. 804.

—— Developments in the Yellow Pine district, Nev.: Min. and Eng. World, Nov. 4, 1911, p. 915.

—— Yellow Pine mill, Good Springs, Nev.: Eng. and Min. Jour., vol. 44, July 13, 1912, p. 68.

—— The Yellow Pine mill: Salt Lake Min. Rev., July 30, 1912, p. 33.

—— Yellow Pine mining district, Nev.: Mexican Min. Jour., vol. 15, No. 6, Dec., 1912, p. 29.

Mineral Resources U. S., 1905, p. 270; 1906, p. 297; 1907, pt. 1, p. 369; 1908, pt. 1, p. 474; 1909, pt. 1, p. 396; 1910, pt. 1, p. 509; 1911, pt. 1, p. 669.

TOPOGRAPHY.

The range called Spring Mountain is a rugged, irregularly shaped group of mountains, separated from the Kingston Range on the south and west by State Line Pass and Mesquite Valley. The mountains have a general north-south trend, but on the west side there are several long, rugged east-west spurs. The east front of the range is marked by very abrupt slopes or cliffs along the great fault. (See Pl. IV.) From Good Springs southward almost vertical cliffs face the northern part of Ivanpah Valley; and from the Potosi-Arden road northward for several miles there is a rise of 4,000 feet to the mile.

The highest point in the vicinity of the mines is Potosi Mountain, at the north end of the district, which has an elevation of 8,500 feet.

The mountains south of this mass are betweeen 5,000 and 5,500 feet above the sea.

The slopes and ridges of the mountain group are rugged, with numerous cliffs formed of the more massive members of the series. The sedimentary rocks are very much faulted and somewhat folded, and as a consequence the numerous dip slopes are of all degrees of steepness. The upturned edges of faulted beds are eroded in a steplike form characteristic of all the ridges on the west side of the range and of the flanks of Table Mountain south of the Good Springs and Sandy road.

The rugged character of the mountains is accentuated by the fact that Mesquite and Ivanpah valleys, on the west and east sides, respectively, are flat, and the mountains have the appearance of a pile of rocks dumped on this floor. Mesquite Valley, a southern continuation of the Pahrump Valley, has an almost level floor at an elevation of 2,650 feet. Its flatness is somewhat relieved by a string of sand dunes along the east side from 1 to 3 miles west of the base of Spring Mountain. The north end of the Ivanpah Valley between Borax and Roach has an elevation of about 2,600 feet. From the valleys rise long, even slopes of débris which near the mountains merge into the alluvial cones at the mouths of the canyons.

There are four intermountain "washes" that have relatively flat topography. The largest of these runs for about 7 miles north and northwest from Good Springs. The next largest is southwest of the Potosi mine, between two long east-west spurs of limestone. The third is west of Shenandoah Peak, and the fourth southeast of Sandy. Most of these intermountain valleys have a decided grade toward the large valleys, but the one north of Good Springs contains several square miles of nearly level ground.

GEOLOGY.

SEDIMENTARY ROCKS.

PREVIOUS INVESTIGATIONS.

The primary object of the visit to the Yellow Pine district was the study of the zinc deposits, and little time could be spared for the study of the stratigraphy of the region.

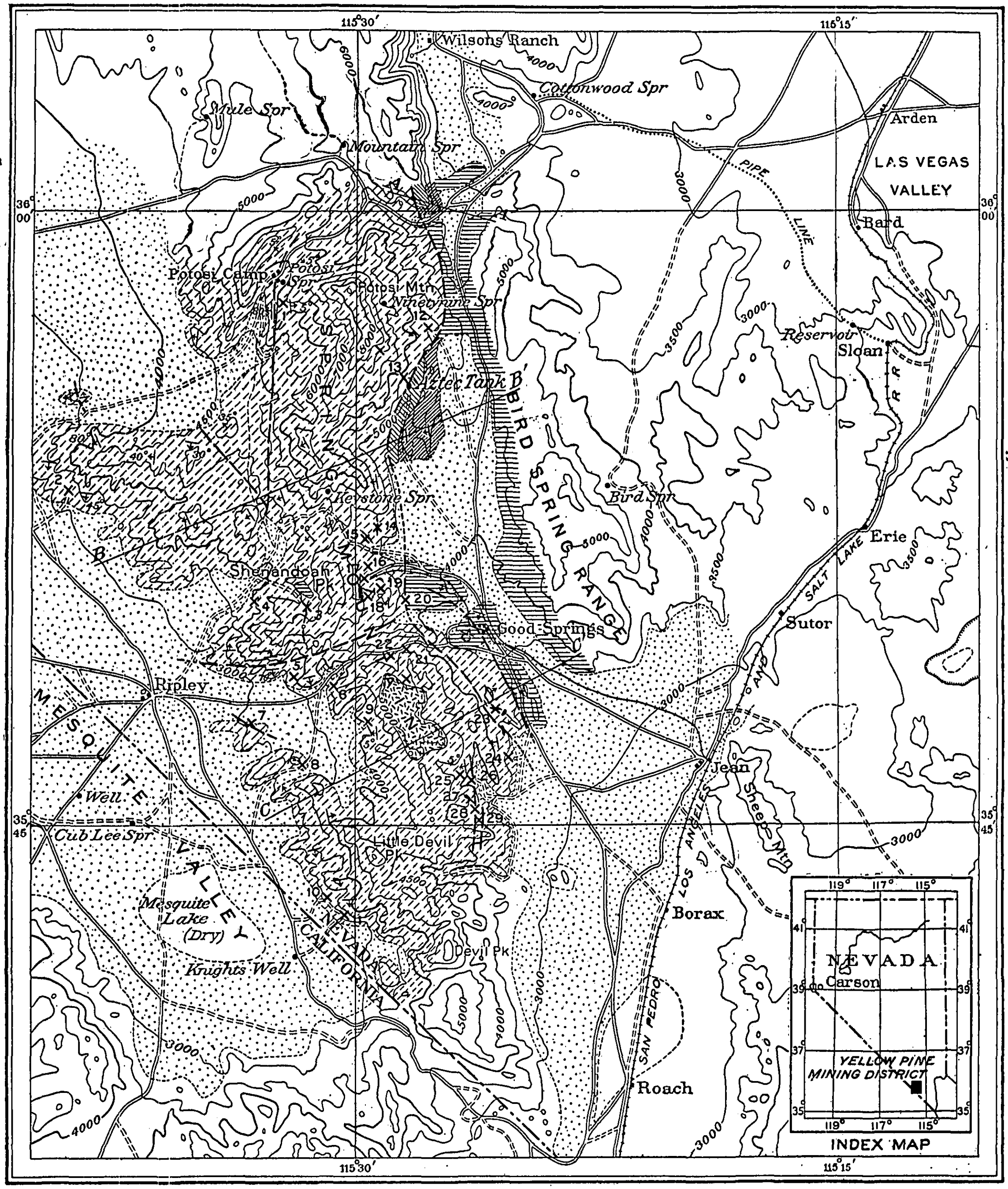
The geologists of the Wheeler Survey visited Spring Mountain and from their reports[1] the following description is abstracted.

They reported that " Carboniferous strata of prevailing gray color and with few exceptions carrying fossils of the age of the coal meas-

[1] U. S. Geol. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 124, 166, 179 180.

LIST OF MINES

1. Potosi
2. Green Monster
3. Keystone
4. Aura Amigo
5. Whale
6. Bill Nye
7. Hoodoo
8. Springer and Tiffen
9. Hoosier
10. Milford
11. Addison
12. Ninety-nine
13. Contact
14. Ninety-three group
15. Red Cloud
16. Prairie Flower
17. Yellow Pine
18. Alice
19. Porphyry Canyon
20. Lavinia
21. Columbia
22. Frederickson
23. Monarch
24. Lincoln
25. Porter
26. Monte Cristo
27. Accident
28. Bonanza
29. Anchor



LEGEND

SEDIMENTARY ROCKS

- Gravel, sand, and recent wash — QUATERNARY
- Light-colored cross-bedded sandstone — JURASSIC?
- Red sandstone and shale — TRIASSIC OR PERMIAN?
- Buff to pink limestone with conglomerate and some sandstone — Pennsylvanian — CARBONIFEROUS
- Massive-bedded light to dark gray limestone — Upper Mississippian ? — CARBONIFEROUS

IGNEOUS ROCKS

- Biotite andesite flows — TERTIARY?
- Intrusive quartz monzonite and granite porphyries — POST-JURASSIC

Fault

Dip and strike

Mine or prospect (*Numbers refer to list of mines*)

Line of structure section (A A′)

0 1 2 3 4 5 6 7 8 9 10 MILES

Contour interval 500 feet.

SKETCH MAP OF THE YELLOW PINE MINING DISTRICT, CLARK COUNTY, NEV.

ures" were present in great volume in Spring Mountain. Potosi (Olcott) Mountain they reported as composed almost exclusively of limestones containing "Lower Carboniferous" fossils, but fossils collected near Mountain Springs were found to include species older than Carboniferous. They reported Jurassic limestones near Good Springs, and gave the following section on Cottonwood Creek, 20 miles west of Las Vegas, which shows massive sandstone above the limestone:

Section on east front of the Spring Mountain Range, 20 miles west of Las Vegas, Nev.; Cottonwood Creek.[1]

[Only limestone measured. Above the massive sandstone (1) is a dark-gray limestone, not examined in place.]

		Feet.
1. Massive red and yellow sandstone:		
(*a*) Yellow	250	
(*b*) Red	150	
(*c*) Yellow	200	
(*d*) Red (shaly)	400	
	——	1,000
2. Bedded fine-grained to saccharoidal limestone, gray and cream-colored; beds separated by shaly layers, so as to weather in steps. Fossils: Phillipsia (?), Macrocheilus (non des.), Naticopsis, Aviculopecten, Avicula, Meekella, Myalina, *Productus semireticulatus*, *Spirifer lineatus*, *Athyris subtilita*, Synocladia		500
3. Massive gypsum, white and red, in lenticular masses		0–75
4. Gray massive cherty limestone:		
(*a*) Limestone; fossils Meekella, Productus, Chætetes, Syringopora	250	
(*b*) Unseen; red (shale?)	25	
(*c*) Limestone	200	
	——	475
5. Friable sandstone, in places shaly or marly; variegated with brilliant iron colors		350
		2,400

In 1900 and 1901 the late R. B. Rowe spent some time in a detailed stratigraphic study of Spring Mountain, but he died before his material was published. J. E. Spurr made use of his notebooks in the preparation of the section devoted to Spring Mountain in Bulletin 208.[2] As the material incorporated in that bulletin was fragmentary, it was the hope of the present writer that more detailed information from Mr. Rowe's notebooks could be used in the present paper, but at the time of writing these notebooks could not be found.

[1] This section was probably taken from the cliffs north of Cottonwood Spring, in the extreme north central part of the area shown on Plate IV.—J. M. H.

[2] Spurr, J. E., Geology of Nevada south of the fortieth parallel: Bull. U. S. Geol. Survey No. 208, 1903, pp. 164–180.

CARBONIFEROUS ROCKS.

UPPER MISSISSIPPIAN (?) STRATA.

The main mass of Spring Mountain south of the Potosi-Arden road is made up of rather thick bedded gray to bluish-gray limestones with a few thin beds of dense gray-black limestone. Much of the limestone appears to be pure and a rather large proportion of it is more or less crystalline. Chert is not abundant at any place but is found in small nodules in certain beds all over the area studied. Fossils are rather abundant in the noncrystalline limestones, but the writer did not collect them at all places where they were seen. The thickness of this series was not measured, and doubtless there is much repetition of beds due to the faulting and folding of the mountains.

From the data at hand it would seem that this series of limestone is 1,500 feet and possibly 3,000 feet thick.

Fossils were collected from seven localities in this limestone and the species determined by G. H. Girty, as follows:

Lot 616 was collected from the light-gray limestone immediately above the ore horizon at the Milford mine (No. 10, Pl. IV). It contains the following species:

Zaphrentis sp.
Lithostrotion? sp.

Lot 617 was collected from a small ridge on the ground of the Ninety-three group (No. 14, Pl. IV). It contains only Zaphrentis sp.

Lot 618 is a collection from the flat-lying limestones immediately above the Potosi tunnel (No. 1, Pl. IV). The following species have been identified:

Zaphrentis sp.
Lithostrotion? sp.
Echinocrinus sp.
Fenestella sp.
Diaphragmus elegans?
Orthotetes kaskaskiensis?
Spirifer keokuk var.
Euomphalus sp.
Paraparchites sp.

Lot 620 was obtained from a dark bluish-gray limestone above cherty limestone that is about 500 feet west-southwest of the Ninety-nine shaft (No. 12, Pl. IV). The species in this bed are:

Aulopora sp.
Crinoidal fragments.
Spirifer keokuk var.
Spirifer aff. arkansanus?
Spiriferina aff. spinosa?
Composita? sp.

Lot 622 was collected from a thick blue-gray limestone that is exposed on the cliff south of the Monte Cristo (No. 26, Pl. IV) and north of the Accident (No. 27), at an elevation of approximately 4,000 feet. The species are:

Lithostrotion? sp.
Batosomella sp.
Lingulidiscina sp.
Chonetes sericeus?
Productus pileiformis.
Productus aff. arkansanus.
Productus moorefieldianus.
Dielasma? sp.
Spirifer keokuk var.
Spiriferina spinosa?
Hustedia mormoni.
Composita subquadrata.
Aviculopecten sp.
Strophostylus aff. carleyanus.

Lot 623 was collected from the flat-lying, somewhat crystalline buff limestones just west of the Hoodoo mine (No. 7, Pl. IV). It contains the following species:

Zaphrentis sp.
Syringopora sp.

Lot 624 was collected in very dark gray dense limestone immediately over the ore-bearing limestone at the Green Monster mine (No. 2, Pl. IV). The following species were recognized:

Zaphrentis sp.
Syringopora sp.
Derbya? sp.
Chonetes sp.
Camarotœchia sp.
Composita? sp.
Euphemus? sp.

Mr. Girty, in his report on these fossils, says:

With the possible exception of lot 624, the remaining lots, so far as they are adequate for definite opinion, have a common facies. * * * The age of this fauna I am inclined to call upper Mississippian, but not with entire confidence. It has the general facies of some of the upper Mississippian faunas without containing any really diagnostic species. The only fact really opposed to this reference is the presence in one of the collections of the Pennsylvanian species *Hustedia mormoni*, but I have identified that species in the upper Mississippian of Arkansas. With this exception there is nothing in the fauna strongly suggesting Pennsylvanian, and the facies, as a whole, is not like the Pennsylvanian faunas which I know. Lower Mississippian (Madison) faunas have been identified in the same general region and this facies is so different that it is safe to say that it is not Madison. A conservative statement seems to be that this horizon may possibly be lower Pennsylvanian in age, but that very probably it is upper Mississippian.

PENNSYLVANIAN STRATA.

The west flank of the Bird Spring Range is composed of light-pink, greenish, and purple sandy and conglomeratic limestones which seem to be entirely similar to those seen in the low hills in the vicinity of Good Springs and to the east of the Good Springs and Monte Cristo road. (See Pl. IV.) Mr. Rowe collected Pennsylvania species from gray, brownish, and pinkish arenaceous limestones about 3 miles northeast of Good Springs.

The low knoll about a quarter of a mile north of Good Springs is composed of brown, pink, and gray-buff arenaceous limestones and limestone conglomerates. The beds strike N. 25° W. and dip 20° SW., apparently forming the northeast limb of a shallow syncline. The following table shows the sequence of these strata, the lowest member being exposed on the north slope of the hill:

Section of strata on knoll north of Good Springs.

	Feet.
Quaternary wash	10
Thin interbedded brownish to pink arenaceous limestones and conglomerates whose pebbles are from one-fourth to one-half inch in size	100
Coarse brownish conglomerate, with pebbles 4 inches or less	30
Cherty light-gray limestone	4
Gray or pink, somewhat cherty arenaceous limestones, in 2 to 10 foot beds. fossiliferous	75

Fossils (lot 621) collected by the writer from the upper part of the lowest limestones in this section comprised the following species, according to Mr. Girty:

Crinoidal fragments.
Fistulipora sp.
Lioclema sp.
Productus aff. humboldti.
Productus semireticulatus var.
Productus sp.
Marginifera sp.
Tegulifera armata?
Squamularia perplexa?
Aviculipecten 2 sp.

Mr. Girty refers this lot to the Pennsylvanian and states: "I think that it is not very high in the series."

TRIASSIC (?) AND JURASSIC (?) ROCKS.

Red sandstones and shales are exposed at the base of the cliffs north of the Potosi-Arden road, shown in figure 23, and in the low hogbacks about 6 miles north-northwest of Cold Springs, shown in section *B–B′*, figure 24. No fossils were collected by the writer from these beds.

Above this series is a yellowish-white, heavily cross-bedded sandstone at least 600 feet thick. These beds form the cliffs shown in section *A–A′*, and are well exposed south of the Contact mine (No. 13, Pl. IV), dipping west toward the great fault. No fossils were collected by the writer from these beds, but Rowe[1] collected Jurassic fossils from them.

Spurr[2] says in regard to the section north of the Potosi-Arden road:

> About 4 miles west of Cottonwood Springs is a great escarpment, at least 2,000 feet high. It consists of two terranes, the lower being red shales and sandstones, making up about one-third of the height. Above this is a heavy yellow sandstone containing occasional red lenses. These rocks are probably Mesozoic.

Spurr[2] gives the following Mesozoic section from Good Springs, but the location is not known:

Section of Mesozoic rocks at Good Springs.

	Feet.
Arenaceous limestone	610
At base, yellowish and reddish sandstone, about 50 feet. Above this are layers of red and yellow shale. This may be the same red terrane which shows at the eastern base of Olcott Peak [Potosi Mountain]	760
Heavy conglomerate	50
Gray limestone, with some layers of red or pinkish arenaceous limestone and abundant layers of chert. The upper 50 feet contains numerous large quartzite bowlders	300

[1] Spurr, J. E., Bull. U. S. Geol. Survey No. 208, p. 174.
[2] Idem, p. 173.

The fossils from the uppermost bed were described by T.W. Stanton as not younger than Triassic and possibly as old as the Permian; those from the lowest bed are questionably referred by G. H. Girty to the Permian.

QUATERNARY DEPOSITS.

Quaternary deposits cover less than half of the area shown on Plate IV. They are composed of very slightly consolidated gravels and sands. Near the mountains these deposits consist of large angular blocks of limestone, except for a small area southeast of the Jurassic (?) sandstone hills 5 miles north of Good Springs, where the wash is composed largely of sandstone fragments. The material becomes finer and finer away from the mountains. These deposits form long, even-sloped cones where they issue from narrow-mouthed canyons, but are thin coverings (5 to 15 feet deep) in the intermountain valleys north of Good Springs and southeast of Sandy. They are clearly the result of transportation by torrential waters and are scored by gullies that are deep near the mountains but dwindle to shallow branching watercourses toward the flats.

In the flat central parts of Mesquite and Ivanpah valleys there are thick deposits of sand which have been formed into low dunes on the east sides of the valleys by the prevailing southwest winds.

STRUCTURE.

GENERAL CHARACTER.

Spurr[1] says that the Spring Mountain range "shows more complex folding than any of the ranges north or east, and to this folding the irregular shape of the range is probably due. * * * In an east-west section the general structure of the range seems to be a broad syncline, with a number of minor folds of little importance. * * * In a north-south section the structure * * * appears to be anticlinal."

The writer visited only the south end of the Spring Mountain Range, in which are located the mines of the Yellow Pine district. In this region the general structure seems to be monoclinal, but it is complicated by numerous faults and some folding. The sedimentary strata of Potosi Mountain have a persistent dip to the west-southwest at fairly low angles. South of the Good Springs and Sandy road the limestones under Table Mountain dip 5°–10° WSW., as far south as an east-west line through the Anchor mine. The monoclinal structure is best seen on the east side of the summit of the range. The ridges extending westward into Mesquite Valley are faulted in a very complicated manner.

[1] Spurr, J. E., op. cit., p. 175.

FAULTING.

Along the east front of the mountains there is a fault which at the Potosi-Arden road brings Mississippian (?) limestone against Jurassic (?) sandstone (see fig. 23) but in the vicinity of Good Springs brings the lower Pennsylvanian against the upper Mississippian (?). This fault is apparently the most profound in the district and will be referred to in this report as the great fault. At the Potosi-Arden road it appears to be nearly vertical, but the exact relations are not known, as the fault is followed by a rather deep canyon. For 4 miles south of the road the fault can not be clearly seen, but it appears to have a north-northeast course.

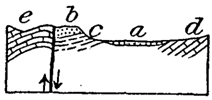


FIGURE 23.—Generalized structure section across the great fault at the Potosi-Arden road, Clark County, Nev., on line *A–A'*, Plate IV. *a*, Quaternary; *b*, Jurassic (?) heavy white sandstone; *c*, Triassic or Permian (?) red shales and sandstones; *d*, Pennsylvanian limestone; *e*, upper Mississippian (?) limestone.

At the Contact mine, about 5 miles south of the road, the great fault was again seen in some mine workings. At this place the blue limestones immediately west of the fault have a very steep dip to the east, but at a distance of 400 feet the dip is nearly as steep to the west. On the southeast flanks of Potosi Mountain, west of the mine, the usual low west-southwest dip of the limestones is well exposed. East of the fault at the Contact mine there are rather thin bedded red sandstones and shales that are similar to those at the base of the cliffs north of the Potosi-Arden road, but about three-fourths of a mile south of the mine white, heavily cross-

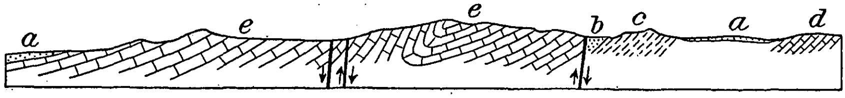


FIGURE 24.—Generalized structure section across the range 4 miles south of Potosi Mountain, Clarke County, Nev., on line *B–B'*, Plate IV. *a*, Quaternary; *b*, Jurassic (?) heavy white sandstone; *c*, Triassic or Permian (?) red shales and sandstones; *d*, Pennsylvanian limestone; *e*, upper Mississippian (?) limestone.

bedded, massive Jurassic (?) sandstone lies east of the fault. (See fig. 24.)

The fault zone itself is as a rule covered by wash, but in one pit about 10 feet east of a distinct outcrop of limestone there is 7 feet of fault breccia containing very small fragments of limestone and red sandstone in a pinkish-gray, sandy matrix that dips 75° W. This breccia zone appears to be about 35 feet wide, though its eastern limit was not certainly placed. The fault is covered from the Contact group south to the Lavina mine. It appears, however, to have a nearly north-south course.

At the Lavina the gray, somewhat crystalline limestones of the Mississippian (?) series are exposed west of the fault with a westward dip of about 45°. East of the fault the light pinkish-gray limestones and conglomerates of the lower members of the Pennsylvanian (?) are seen striking a few degrees west of north and standing nearly vertical or with a very steep dip to the east. Between these two sedimentary formations there are about 200 feet of granite porphyry and 60 feet of fault breccia consisting of fine fragments of limestone and porphyry. The actual wall of the fault was not seen, but several planes of movement, which dip 55° W., are probably parallel with the fault.

Along the east front of Spring Mountain the great fault dips steeply to the west and the beds west of the fissure have been raised relative to those on the east side by compressive stress. The faulting south of Good Springs on the east side of the range is not so clearly thrust faulting, yet it gives that impression.

South of the Lavina mine and north of the Good Springs and Sandy road there is a strong east-west fault zone which runs entirely across the mountains but appears to turn southward along the east front into the great fault.

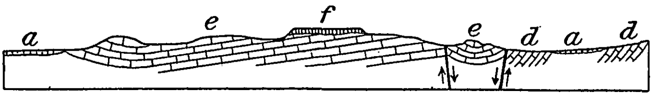


FIGURE 25.—Generalized structure section across Table Mountain, Clark County, Nev., on line C–C', Plate IV. *a*, Quaternary; *d*, Pennsylvania limestone; *e*, upper Mississippian (?) limestone; *f*, biotite andesite flows (Tertiary ?).

In the vicinity of Crystal Pass, 2 miles south of Good Springs, there are two nearly parallel north-northwest and south-southeast faults with smaller displacement than the great fault. (See fig. 25.)

Near the Accident and Anchor mines two small north-south vertical faults cut the upper Mississippian (?) strata.

The east-west ridge at the northeast end of Mesquite Valley, at the west end of which the Green Monster mine is located, shows a most complex system of faults, but time did not permit a study of their relations.

The fault running south from the Potosi mine (No. 1, Pl. IV) appears to lie along the west side of an overturned anticline. (See fig. 24.) This fault is without much question due to compression.

A small thrust fault of about 10 feet heave occurs on the west limb of a low anticlinal fold about half a mile west of the summit on the Good Springs and Keystone road.

The low group of isolated hills 4 miles southeast of Sandy is traversed by a zone of brecciated limestone that is about 200 feet wide and trends N. 70° W. The movement along this zone appears to have been greatest in a horizontal direction, as the limestones on either side of it seem to be of about the same age.

FOLDING.

Folding of the limestone strata appears to have been much less extensive than faulting in the south end of Spring Mountain. The greatest folding noted in the reconnaissance was seen on the northwest flank of Potosi Mountain, along the line *B–B′* of plate IV. At this place there seems to have been an overturned anticlinal fold whose top was pushed over to the east-northeast, forming a tight syncline, as indicated in figure 24. Faulting occurred along the western limb of the anticline and perhaps at other places.

The Potosi Wash, which runs northeast and southwest in the northwest corner of the area mapped on Plate IV, is near the axis of a low anticline whose limbs dip 5° to the northwest and southeast on either side of the head of the canyon, but the structure of the south limb of the anticline west of the Potosi mine is very much complicated by faults.

The east-west fault across the range north of the Good Springs and Sandy road apparently follows the crest of a tightly folded anticline.

The northwest ridge, about 4 miles north of the Milford mine, seems to be the northeast end of an anticlinal fold whose axis plunges to the northeast under the intermountain valley south of the Good Springs and Sandy road.

CHARACTER AND AGE OF DEFORMATION.

The deformation of the south end of Spring Mountain seems to have been due to compressive stresses that acted in an east-northeast direction and resulted in thrust faulting of considerable magnitude and in the overturning to the east-northeast of the top of at least one anticline. With or shortly after this movement there was apparently some north-south compression. The McCullough Range, east of the northern part of the Ivanpah Valley, is largely pre-Cambrian granite, and it is thought that this formed the block against which the stress acted.

The age of the deformation is not certainly known, though it has involved the white cross-bedded sandstones of supposed Jurassic age.

INTRUSIVE IGNEOUS ROCKS.

GENERAL FEATURES.

Intrusive rocks seem to be the exception rather than the rule in Spring Mountain. By far the largest masses are seen in the vicinity of the Yellow Pine mine, though relatively small discontinuous exposures of porphyry are found north of the Lincoln mine in the vicinity of Crystal Pass, as well as at the Red Cloud, Lavina, and Keystone mines. Outside of these few places the sedimentary series so far as seen is apparently undisturbed by intrusions. It is reported that there is a small porphyry dike in the canyon east of the Milford mine, southwest of Little Devil Peak, and another at the May Kirby mine, south of the Keystone.

With the exception of the dikes at the May Kirby mine and east of the Milford mine, all these bodies of porphyry are very close to the great fault which runs approximately north and south along the east front of Spring Mountain.

The porphyry of the May Kirby mine is reported to be fairly continuous, running as far south as the east-west faulted fold which crosses the range west of Good Springs. (See Pl. IV.)

The limestones are much more resistant to weathering and erosion than the porphyry, so that croppings of the porphyry are difficult to trace. The position of the dikes is in places marked by depressions filled with soft decayed porphyry. The igneous areas can not be shown with accuracy on the map, as the outlines are irregular and are in general obscured by loose material.

The intrusions are in the form of short dikes that vary from a few feet to over 300 feet in width and thin sills that follow the tilted beds of the Carboniferous. In detail they are very irregular, a single dike ranging from 2 to 50 feet in width in a short distance. At the Keystone and Alice mines this irregularity is most conspicuous, as there development along the porphyry contacts has been more extensive than at any other places.

Just west of the Bybee mine the porphyry and limestones have been faulted. The dike (?) at this place is about 400 feet wide and is cut by two faults that strike N. 60° W. and dip about 70° N. On the south side of each of these faults the relative movement is to the east. The dike (?) apparently dips to the west nearly parallel to the bedding of the limestone, but as it is not cut in any of the levels of the Bybee mine its true character has not been determined.

PETROGRAPHY.

The intrusive rock in all exposures is much altered, usually to a red-brown color, though near the Bybee mine it is yellowish brown. It is distinctly porphyritic but differs in texture at different places. The most widely distributed variety is composed of pinkish orthoclase crystals from one-eighth to one-fourth inch in largest dimension, with some visible plagioclase crystals and a little biotite, forming about one-third of the rock, the remainder of which is a fine granular aggregate of orthoclase and plagioclase with some quartz. Apatite is a characteristic though not abundant accessory.

This facies is the best preserved of all the igneous rocks, though the thin sections were disappointing in that the plagioclase feldspars and ferromagnesian minerals were too much altered for accurate determination. The slides show phenocrysts of two ages. The earlier are small, well-formed orthoclase, plagioclase, biotite, and augite crystals; the later are all orthoclase crystals zonally built and reaching a maximum size of half an inch. Phenocrysts of the first crystallization are included poikilitically in the larger crystals. The ground mass is in excess of the phenocrysts and is composed of microcrystalline orthoclase, plagioclase, and some ferromagnesian mineral, possibly biotite, now largely altered to sericite. Here and there a little quartz is present in the groundmass. This rock is a quartz monzonite porphyry approaching granite porphyry in composition.

A different facies of the intrusive rock is exposed near the Alice mine, south of the Bybee. The rock is very coarsely porphyritic, containing beautifully developed orthoclase crystals as much as 1½ inches in diameter. These usually show zonal growth and are twinned according to the Carlsbad law. In this rock there are also rounded quartz phenocrysts a quarter of an inch or less in diameter, resembling pebbles.

This facies likewise contains phenocrysts of two ages, but there appears to be comparatively little plagioclase feldspar in the rock, which has therefore been called a granite porphyry.

There seems to be little doubt that this granite porphyry is a variation from the quartz monzonite magma rather than a distinct intrusion, though proof of this was not found.

ALTERATION OF THE IGNEOUS ROCKS.

Both the quartz monzonite porphyry and the granite porphyry are highly altered. This alteration consists of a more or less complete sericitization of the ferromagnesian minerals, accompanied by the development of iron oxide, which gives the yellow and red colors to the rock. The feldspars, both plagioclase and orthoclase, are altered to sericite and quartz. The quartz phenocrysts are somewhat strained and cracked, but not otherwise altered, and the apatite remains clear even where the rocks show the most change.

CONTACT METAMORPHISM.

There has been almost no contact metamorphism of the limestones, even at the borders of the porphyry intrusions. The contacts in most places are very sharp, and the texture of the porphyry is almost uniform from side to side of the largest dikes.

At one place about half a mile south of Crystal Pass a narrow sill of porphyry is intruded into a granular dolomitic (?) limestone which for 6 inches above the contact contains some seams of magnetite now largely altered to hematite and limonite. This material is said to carry about $10 a ton in gold. The porphyry at this locality occurs both as dikes and sills and contains small bunches of magnetite 2 inches or less in diameter.

At the Keystone and Red Cloud mines the limestone in immediate contact with the porphyry is slightly silicified and cut by narrow quartz stringers, but there is no other alteration of the sedimentary rock.

AGE OF INTRUSION.

The quartz monzonite porphyry and granite porphyry in most places are intrusive into the massive blue limestones that are probably of upper Mississippian age, and the largest areas of the intrusive rock are localized along the great fault, which occurred later than the deposition of the Jurassic (?) sandstone. Near the Lavina mine there are small dikes of quartz monzonite porphyry in the lower Pennsylvanian east of the great fault. The intrusion is therefore considered to have taken place after the faulting. Another feature which points to the same conclusion is that the dikes cut across the bedding of the limestones at whatever angles they now rest. The porphyry has been faulted, as is well shown at the Bybee, Keystone, Lavina, and Red Cloud mines, but it has not been disturbed or crushed to any such extent as it would have been had the intrusions taken place previous to the main deformation of Spring Mountain. The intrusion is therefore considered to be at least post-Jurassic in age and is possibly to be correlated with the granodiorite and monzonite intrusions of the Sierra Nevada.

EXTRUSIVE ROCKS.

GENERAL FEATURES.

The only places where extrusive igneous rocks were found in this district are on Table Mountain southwest of Good Springs, south of the Good Springs and Sandy road, and in one very small area about 5 miles southeast of Sandy.

The flows on Table Mountain cover an area of about 3½ square miles. The lower limit of rock of this type is at an elevation of 4,900 feet and is apparently at the same level on all sides of the mountain. The flows are essentially horizontal and overlie the tilted beds of the upper Mississippian (?) section. The sedimentary beds in this section, however, have a dip of only 10° W., and it was not determined whether the flow rocks rest on a single bed throughout or whether they overlap the eroded edges of several beds.

The exposure 5 miles southeast of Sandy covers an area of about 100 square feet and has the appearance of being composed of fragments of porphyry rather than of being part of a flow. The rock is similar to that of the flows on Table Mountain.

So far as known, none of these flows have suffered any faulting or folding.

PETROGRAPHY.

The flows have a total thickness of 110 to 150 feet. The lower half to two-thirds of them are light gray to reddish gray in color; the uppermost flows are dark and some are black. Most of the rock is vesicular, though at least one flow is a dense porphyry with a glassy base.

Under the microscope all these flows are seen to be very similar in mineral composition, though the proportions of the component minerals are different and the ratio of groundmass to phenocrysts varies widely. Most of the phenocrysts are small, well-formed crystals of andesine or labradorite that in a number of thin sections do not show any albite twinning, though most of them are twinned according to the Carlsbad law. Small, well-developed crystals of brownish biotite are next in number, but in all the slides they are somewhat altered to iron oxide. Augite is present in minor amounts in all the flows, the crystals being much smaller than those of the other phenocrystic minerals and as a rule not so well developed.

The groundmass is composed largely of minute microscopic plagioclase laths, together with magnetite and what appear to be small shreds of biotite. The crystals in the groundmass have a more or less concentric arrangement around the phenocrysts, due to flowage. In one slide the groundmass is seen to be partly glassy, but this is not the general rule.

The color of the rocks is probably due to the abundance of the biotite and to its degree of alteration. The gray rock contains much less biotite than the black rock, and the reddish flow is between the two extremes in the amount of biotite, with the difference that this ferromagnesian mineral is almost completely altered to iron oxide.

AGE OF EXTRUSION.

The age of these flows can not be determined in this particular area. They are most surely younger than the faulting and tilting, which has been shown to be post-Jurassic, and they are possibly to be correlated with the Tertiary period of volcanic activity common in western Nevada.

ORE DEPOSITS.

TYPES AND GENERAL MODE OF OCCURRENCE.

There are two distinct types of ore deposits in the Yellow Pine district. The more important is the replacement type, comprising deposits of zinc-lead and copper in upper Mississippian (?) limestone. The other type, which for some years was of importance, comprises the gold deposits in altered igneous rocks.

The lead mines were discovered first and from 1860 to the present time have been more or less continuously exploited. The Keystone gold mine was operated for several years previous to 1906, but in 1912 no gold mines were worked. Since the discovery of the zinc minerals in 1906 the greatest development has been in bodies of mixed zinc and lead ore.

The ore deposits of the replacement type can be divided into deposits of zinc and lead carrying some silver and deposits of slightly auriferous copper. The zinc-lead group can be still further subdivided into two overlapping types—one set consisting essentially of zinc minerals with little or no lead and the other containing argentiferous lead, but practically no zinc. These two types are distinct in a few places, but in most of the mines the ores are of the mixed zinc-lead type, though the proportion of one set of minerals to the other may be widely different in the same ore body. Some of the purely zinc-lead mines contain bodies of copper, but usually these are very small and of little importance.

There are only a few mines and prospects of copper ores alone, and these, with one exception, are on the east side of the mountains, not far removed from the great fault.

The replacement deposits seem to have little relation to the few intrusive igneous rocks in Spring Mountain, as a large number of the ore bodies are found in the limestone at a considerable distance from any known porphyry. It is true that some of the mines, notably the Bybee and Prairie Flower, are located very near masses of igneous rock, but the greater number of the mines are remote from any known intrusives.

The gold ores of Spring Mountain are found in the intrusive quartz monzonite and granite porphyry or at the contact. The Keystone deposit is the best example of gold ores in altered porphyry, and the Monarch group south of Crystal Pass shows the type of deposit at the contact.

REPLACEMENT DEPOSITS.

ZINC-LEAD DEPOSITS.

OCCURRENCE.

The zinc-lead deposits of the Yellow Pine district are very irregular replacement bodies which usually occur in more or less crystalline limestone and have been found, with one exception (the Hoosier), in the immediate vicinity of fractures or folds. No deposits have been discovered east of the great fault or in limestones younger than the upper Mississippian (?) limestones.

The Bybee and Prairie Flower ore bodies are in upper Mississippian (?) limestone near the contact of intrusive quartz monzonite or granite porphyry, but the rest of the lead-zinc mines here described are situated where no intrusive igneous rock has yet been found. The ores occur through a vertical range of 3,000 feet; at the Potosi mine they lie at an elevation of approximately 6,000 feet, and at the Milford mine at 3,000 feet.

The faulting and folding of Spring Mountain is complex and time did not permit a careful study of the structure, but it seems to be fairly certain that the ore deposits are not restricted to any paricular bed of limestone. At the Potosi mine the barren zones are dense thin-bedded dark limestones with some shale, and at the Green Monster and Milford the ore does not occur in the dense cherty dark limestone that is interbedded with the light-colored ore-bearing crystalline limestones. As a rule, the more highly crystalline the limestone the greater has been the ease of replacement, but there are exceptions to this generalization.

Th principal factor in determining the location of the ore bodies appears to have been the presence of fractures of small or large extent that in general strike east and west or nearly north and south and stand in many places almost vertical. The mineral-bearing waters moved with more ease along these openings than through the rock. They deposited their content in part in the open fissures, but they have also caused the replacement of certain beds of limestone for some distance from the fractures.

As a consequence of the location of the ore bodies near practically vertical fissures, the vertical dimension of many of them is greater than either of the horizontal measurements. At the Hoosier mine, however, the ore is in a flat tabular body in a particular bed of crystalline limestone which, in the vicinity of the mine, does not appear to have been disturbed by faulting. At the Bybee mine the upper ore body has greater horizontal than vertical extent, but at each end this body merges into others with large vertical dimensions. The border between ore and barren rock is everywhere irregular, but the transition zone in all the properties visited is less than 2 feet in width and at many of them the line between ore and waste is sharp.

VARIATIONS IN THE DEPOSITS.

The lead and zinc ores are as a rule very closely associated—that is, in practically all the zinc ores there is more or less lead. The ratio of lead to zinc is extremely diverse, even in a single ore body. At the Bybee it has been fairly well established that there is a greater lead content in the ore above the 300-foot level than below it, and at the Milford and Addison mines there is a marked decrease in lead below a depth of 50 feet. The ore at any particular level is also subject to wide variation in the relative proportions of lead to zinc. In some places the ore may be exclusively zinc and near by it may be half lead and half zinc, or largely lead. At the Bonanza mine (No. 28, Pl. IV) there is a distinct deposit of lead ore and an equally clean and distinct deposit of zinc, separated by about 150 feet of limestone. The Ingomar mine is said to produce practically pure lead ore. Clean zinc ore with almost no lead is found at the Monte Cristo and in stopes of several of the other mines.

MINERALS OF THE DEPOSITS.

With two exceptions the minerals of the zinc-lead deposits of the district are those belonging to the oxidized zone. Galena is present in subordinate quantities in all the mixed ore and in the purely lead deposits. The only occurrence of a zinc mineral belonging to the sulphide zone noted was at the Potosi mine, where there is a small undeveloped body of sphalerite surrounded by carbonate ores.

In the following paragraphs will be found a brief description of the minerals of the zinc-lead deposits, arranged in the order of their importance.

Zinc carbonate.—Smithsonite, $ZnCO_3$, which is usually spoken of simply as "carbonate" or "dry bone," contains theoretically 52 per cent of metallic zinc. The better grades of commercial carbonate run from 35 to 40 per cent of zinc. The mineral assumes a variety of forms, the most common one in the Yellow Pine district being an earthy material stained brown to red by iron oxide and having the appearance of somewhat consolidated sand. Some of the ore consists of massive hard white smithsonite which has a high specific gravity, nearly equal to the theoretical 4.3 to 4.5 of the pure mineral, and which shows in places a beautiful banded structure. Another variety is in banded form, the ore having been deposited in successive layers in open cavities; this variety may contain considerable hydrozincite. Here and there small well-developed crystals of smithsonite are seen in druses in the massive ore. These are small rhombohedrons that resemble calcite in form.

Lead carbonate.—Cerusite, $PbCO_3$, locally called lead carbonate or "sand carbonate," contains theoretically 77.5 per cent of metallic lead. Its usual mode of occurrence is in small semiporous masses of gray, brown, and yellow color surrounding kernels of unaltered galena in the zinc carbonate ore. Much of it is in very fine grains distributed all through the zinc ore, making hand sorting impossible. At a few places small stopes of lead carbonate have been mined, and at the Bybee mine, in the north stopes on the first level, there are some large bodies of pure gray cerusite which has the typical pearly luster of that mineral. At the Potosi mine a few very small fibrous white crystals of cerusite were found in a druse in massive gray lead carbonate. In the Yellow Pine district the cerusite is usually argentiferous—in fact, the silver produced in the district is derived chiefly from the galena and the cerusite.

Lead sulphide.—Galena, PbS, often spoken of as "lead" or "sulphide" in the Yellow Pine district, theoretically carries 86.6 per cent of metallic lead. Its usual mode of occurrence is as small masses surrounded by anglesite and cerusite in the smithsonite. Some of these masses show a roughly cubical outline of crystalline galena, but most of them are very irregular. The cubic cleavage is always well shown, even in the most irregular masses. At the Bonanza mine (No. 28, Pl. IV) there is a deposit of almost pure galena and cerusite. In the sphalerite ore from the Potosi mine there is a small proportion of galena intergrown with the zinc ore.

Zinc silicate.—Calamine, $(ZnOH)_2SiO_{32}$, theoretically contains 54.2 per cent of metallic zinc. In the Yellow Pine Co.'s mines it is usually found lining cavities in the other ores. At the Potosi and Bybee beautifully clear white tabular crystals of small size are found along watercourses. At the Monte Cristo mine brownish calamine is mixed with smithsonite along the western postmineral fault. This mineral is also seen in thin seams between laminæ of smithsonite in some of the banded ore from the Monte Cristo and Milford mines.

Hydrozincite.—Hydrozincite, $ZnCO_3.2Zn(OH)_2$, is the hydrous form of smithsonite, sometimes called "zinc bloom." It has a white or yellow color, an earthy texture somewhat resembling that of chalk, and a specific gravity notably lower than that of smithsonite. Theoretically it carries 60 per cent of metallic zinc. It occurs as thin white coatings on smithsonite near the surface at most of the mines and is found in fairly large masses at the Potosi and Bybee. The largest stope of this mineral seen in the district was on the first level of the Bybee mine, southwest of the shaft. (See fig. 27, p. 265.) The croppings of most of the zinc-lead deposits are marked by soft white chalklike hydrozincite with more or less cerusite and a yellow lead stain that is probably pyromorphite.

Lead sulphate.—Anglesite, $PbSO_4$, theoretically contains 73.6 per cent of PbO. In the Yellow Pine district it occurs only as thin coatings about kernels of galena and as streaks cutting that mineral. It has a black, somewhat waxy appearance quite different from the metallic lead-gray of the galena, from which it is readily distinguishable.

Lead phosphate.—Pyromorphite, $Pb_3Cl(PO_4)_3$, a yellow earthy material derived from the alteration of galena, is found at the Singer and Tiffin mines. It is seen in very small amounts mixed with cerusite, hydrozincite, and smithsonite in the croppings of other zinc-lead deposits. At the Beck mine (No. 8, Pl. IV) the mineral is fairly abundant and has been supposed to contain uranium.

Zinc sulphide.—Sphalerite, ZnS, was found in the Yellow Pine district only at the Potosi mine. It occurs here at one place on the first level above the main tunnel. The blende is in crystals as much as one-fourth inch in diameter intergrown with a small amount of calcite and a little galena. It is dark brown to black in color and was developed contemporaneously with the calcite and galena. It is altered to smithsonite around the borders.

COPPER DEPOSITS.

OCCURRENCE.

The copper ores mined in the Yellow Pine district are entirely those characteristic of the zone of oxidation, being oxide, carbonate, and silicate minerals. In their occurrence they somewhat resemble the zinc-lead ores, with the difference that the copper mineralization has been not nearly so strong. The copper deposits are as a rule clearly distinct from deposits of other minerals, yet in some fractures, cutting the zinc carbonate ore bodies, there are small deposits of copper carbonates. It therefore seems as if these deposits, at least, are younger than the secondary lead-zinc mineralization.

The four copper mines visited by the writer in the fall of 1912 are the Ninety-nine, Columbia, Lincoln, and Aura Amigo. Besides these there are several prospects south of the Ninety-nine and north of the Red Cloud which have good surface showings, and it is reported that at the Double-up mine there is a fair-sized body of copper ore. In the zinc-lead mines small bunches of copper carbonates are not uncommonly opened, but they constitute a very small part of the ore of those mines. The mines having strictly copper ores, so far as developed, are, with the exception of the Aura Amigo mine (No. 4, Pl. IV), on the east side of Spring Mountain and not far removed from the great fault.

The occurrence of the copper deposits, like that of the zinc deposits, seems to be determined largely by the presence or absence of fracture planes. They are typical replacement bodies and as a rule the boundaries between ore and waste are much less well defined than the walls of the zinc-lead deposits.

At both the Ninety-nine and Columbia there seems to be a decided tendency for the ore to decrease in copper content with increasing depth. At the Ninety-nine mine the ore is strong to a vertical depth of 260 feet, along a nearly vertical east-west fracture. At the Columbia, whose ore body makes along a nearly flat southward-dipping east-west fault, the mineralization is decidedly weaker at a depth of 70 feet than at the surface. At the Lincoln mine practically the only body of ore of workable size did not extend beyond a depth of 25 feet.

MINERALS OF THE COPPER DEPOSITS.

The copper ores are those typical of the zone of oxidation. They are all said to carry a small amount of gold. The following minerals arranged in the order of their importance were found in the copper ores of the district.

Red copper oxide.—Cuprite, Cu_2O, whose theoretical copper content is 88.8 per cent, is rarely found pure in the Yellow Pine district. It usually occurs with iron oxide in dull brownish-red to red earthy masses mixed with more or less of the carbonate minerals.

Hydrous copper silicate.—Chrysocolla, $CuSiO_3.2H_2O$, occurs as bluish-green incrustations on the red oxide, together with the carbonates.

Copper carbonate.—Malachite, $Cu_2(OH)_2CO_3$, in bright-green small masses and thin crusts, locally with a silky fibrous structure, is found intermixed with chrysocolla and azurite on the red oxide ore.

Hydrous copper carbonate.—Azurite, $Cu_3(OH)_2(CO_3)_2$, occurs as dull earthy bright-blue patches with malachite and chrysocolla.

Copper glance.—Chalcocite, Cu_2S, occurs in ore from the Ninety-nine mine, which contains some small kernels of black metallic chalcocite surrounded by the red oxide and carbonates. It is also reported that some of the Columbia ore contained this mineral, though none was seen in the mine or on the dump.

Copper phosphate.—Liebethenite (?), $Cu_2(OH)PO_4$, was found as a very thin crust of dark olive-green color on a specimen of ore from the incline at the Aura Amigo mine on the west side of the mountains.

SOURCE OF THE COPPER.

The only primary mineral-carrying copper found in the district is "cupriferous pyrite," in the gold ore at the Lavina mine. This ore is clearly associated with the quartz monzonite-granite porphyry intrusion. At the Keystone mine no sulphide ore is to be seen, but there are what appear to be casts of pyrite in some heavily iron-stained altered quartz monzonite porphyry, and some of the ore is stained by copper carbonates. As the original gold ores were "cupriferous pyrite," it seems probable that the copper of the replacement bodies may have been derived from them. Whether the copper in the so-called cupriferous pyrite occurs chemically combined in the pyrite or as chalcopyrite was not determined.

GANGUE MINERALS OF THE REPLACEMENT DEPOSITS.

As a general rule there is no real gangue in the zinc-lead ores. Limonite and red iron oxide are present, but these can hardly be considered gangue minerals in the sense in which that term is ordinarily used. Most of the zinc-lead ore bodies contain small masses and ribs of unaltered limestone which the miners of the district sometimes call gangue, though it is not gangue in the strict sense. At a few places there are small bodies of white calcite which is strictly a gangue mineral.

In the copper deposits the gangue is calcite, which may be white, green, or pink. The color is due to the presence of minute quantities of red copper oxide in the pink variety, at the Columbia mine, or to copper carbonate in the green variety, found in the Lincoln mine.

Two other minerals ordinarily spoken of as gangue minerals were noticed in the district. In the sphalerite ore body of the Potosi mine there are some small crevices lined with minute soft tabular crystals of gypsum (calcium sulphate, $CaSO_4$).

Heavy spar (barite, $BaSO_4$) occurs in coarsely crystalline form about three-fourths of a mile north of the Red Cloud mine, as a 1-foot bed that was cut in a shallow shaft on one of the claims belonging to Richard Feaster. This was the only occurrence of the mineral noted, but it is possibly of wider distribution.

ORIGIN OF THE REPLACEMENT DEPOSITS.

GENERAL MODE OF OCCURRENCE.

The replacement ore bodies, as before stated, occur near fissures along most of which there has been some movement. There are two fairly persistent sets of fractures. One strikes about east and west and either stands nearly vertical or dips to the south at medium angles. The other set strikes from N. 20° W. to N. 20° E., though the majority of the fractures depart from the true north-south line at smaller angles than these extremes. Nearly all these fractures, so far as seen, are vertical or have a very steep dip either east or west. The ore bodies make in large and small irregular masses along the fractures and penetrate beds of crystalline limestone adjacent to the fractures, as replacements.

The ores so far mined are all carbonates of lead and zinc, with some zinc silicate and lead sulphate and varying amounts of galena. They are typical ores of the zone of oxidation.

The deepest mine working in the district, at the Keystone, has reached a vertical depth of at least 700 feet and has been absolutely dry throughout. The Bybee has attained a vertical depth of at least 300 feet and shows no sign of moisture. The depth of the ground-water level is not known.

CHARACTER OF THE ORIGINAL DEPOSITS.

There is only one place where there is even a suggestion of the original character of the mineralization. At the Potosi mine, 65 feet above the main tunnel level, there is a small body of sulphide ore which is thought to be a remnant of the original ore that may be enriched. It is not certain, however, that this body may not be a deposit of secondary sulphides, but it is thought to represent the original ore. This ore consists of rather massive dark-brown to black sphalerite set in a matrix of calcite, with small crystals of galena. That the sphalerite contains a large amount of iron is beyond question.

CHARACTER OF THE PRESENT ZINC-LEAD ORES.

Most of the ore bodies that are being mined consist of irregular masses of iron-stained smithsonite with a relatively small proportion of galena as kernels, surrounded by a thin band of anglesite, outside of which there is a greater or less amount of cerusite. Some deposits consist of almost pure white smithsonite with a little calamine, but even these contain some iron-stained ore. Strictly lead deposits are sometimes found consisting of galena, anglesite, and cerusite.

ORIGIN OF THE ZINC-LEAD ORE BODIES.

It is the belief of the writer that the ores of the Yellow Pine district were derived entirely from bodies of sulphide ore whose mode of deposition is not definitely known, though they are thought to have been replacements. This primary ore, to judge from the single occurrence at the Potosi mine, consisted of iron-bearing sphalerite and small quantities of galena in a matrix of calcite. If ore of this kind were brought into the zone above water level, the processes of oxidation, carbonation, hydration, and solution characteristic of the belt of weathering would take place. Lead sulphide and zinc sulphide by simple oxidation would be changed to lead sulphate ($PbSO_4$) and zinc sulphate ($ZnSO_4$). The former, deposited as the mineral anglesite, is now found surrounding kernels of unaltered galena. If these sulphates react with calcium carbonate ($CaCO_3$), lead carbonate and zinc carbonate are formed according to the following equations:

$$PbSO_4+CaCO_3=PbCO_3+CaSO_4.$$
$$ZnSO_4+CaCO_3=ZnCO_3+CaSO_4.$$

The presence of the red iron-oxide stain in much of the ore is explained by the breaking down of the iron-bearing sphalerite, the iron going into solution probably as sulphate, to be deposited as the hydrated oxide limonite.

Galena is much more stable than sphalerite in the zone of oxidation, and its occurrence in larger amounts in the upper parts of many of the mines is due to this fact. It has been concentrated there by the solution and carrying away of a larger proportion of the zinc minerals.

It is thought that the present bodies of carbonate ore have resulted in part by alteration in place and in part from a downward concentration of the metals by surface waters that followed the fractures as the easiest paths in their movement toward the ground-water level. These strongly mineralized solutions have precipitated the zinc and lead in the more pervious crystalline limestone beds, or in zones of crushed limestone along fault planes.

GOLD DEPOSITS.

The purely gold deposits of the Yellow Pine district are less than ten in number, and of these only four were visited. These represent three types of deposits between which there seem to be all gradations. The Keystone and Red Cloud represent one type in which the gold occurs free, disseminated in very much altered quartz monzonite porphyry. At the Monarch group, south of Crystal Pass, the gold occurs free with thin seams of magnetite, now partly altered to limonite, that are found between limestone and altered quartz monzonite sills. The ore at the Lavina mine consists of stringers of quartz, calcite, and cupriferous pyrite, occurring in a zone of brecciated limestone and quartz monzonite porphyry but usually in that part of the zone near the altered though uncrushed porphyry. The quartz in these stringers is all strained by crushing since its formation and some of the calcite is fragmental. The pyrite and some calcite form the matrix of the other constituents.

From the foregoing it seems likely that the gold ores were originally formed by ascending, probably hot waters that probably closely followed the intrusion and solidification of the quartz monzonite porphyry magma. The gold was originally associated with pyrite or slightly cupriferous pyrite. When this material was brought into the zone of weathering the sulphides broke down. Iron and copper went into solution and probably most of this solution was carried away, but some of the iron and a little of the copper were left in the altered quartz monzonite porphyry, forming the brownish stain and at a few places the greenish copper carbonate minerals. These waters were somewhat siliceous, for they have deposited quartz in small cracks in the adjacent limestone and have in general caused a slight silicification by replacement of the limestone immediately at the contact. The gold in the present ores is in very small flakes and is of a rather light yellow color, apparently carrying considerable silver. The tenor of the ores is usually low, generally not exceeding $60 a ton and averaging between $15 and $20 for the grade of ores so far mined.

ECONOMIC CONSIDERATIONS.

PRODUCTS OBTAINABLE.

The Yellow Pine district has a varied production. Exclusively gold ores are obtained from at least four different mines. There is also some opportunity for the development of prospects which may yield various oxidized copper ores that are said to carry a little gold. By far the most important mines at the present writing are those from which oxidized zinc and lead ores are obtained. These produce three classes of ore, namely, lead ore, zinc ore, and zinc-lead ore, each one of which requires different treatment. All three classes may be taken from a single mine or they may be found in distinct deposits.

The lead ores—galena, cerusite, and anglesite—are found fairly clean in considerable amounts. They carry silver and are readily salable to any of the lead-smelting companies in the Western States, though the market for ore of this kind is now almost entirely restricted to the companies with smelters at or near Salt Lake City, Utah.

The zinc ore, consisting of mixed smithsonite, hydrozincite, and calamine, is found practically free from galena at many places in the district. So far as known the silver content is very low in all this ore. This grade is most acceptable to the zinc smelters of the Mississippi Valley and has of late found a market with the manufacturers of zinc-white paint pigments.

The mixed zinc-lead ore found at the Potosi, Bybee, and numerous other mines can not be sold at a profit to the miner without some sort of separation. Previous to 1911 all ore of this grade was sorted by hand into the two products, but it was realized that there was of necessity a large loss in the fine material which could not be sorted by picking. The new Yellow Pine mill has demonstrated that this ore can be separated by mechanical means and the products, lead concentrates and zinc tailings, disposed of to the smelting companies.

MILLING.

Three mills have been built in the Yellow Pine district. One of these was a cyanide mill for the treatment of gold ores, and the other two were used for treating zinc-lead ores.

The Keystone mill at Sandy is equipped with two 4-foot Huntington mills for crushing the soft altered porphyry ores and with iron leaching tanks. At the Red Cloud mine an unsuccessful experiment was made at cyanidation.

The mill now used by the Yellow Pine Co. was originally built by the Mineral Union Co. (Ltd.), in 1900, as a leaching plant to recover silver and lead from the complex ores of the district. It did not prove successful and was allowed to remain idle for several years. In 1911 the Yellow Pine Co. began the alteration of the mill to a concentrating plant for treating the mixed lead-zinc ores of the Bybee mine. The mill is rather a separating than a concentrating mill, for all the products are marketed except a very small amount of waste rock taken from the picking belt. What are ordinarily called concentrates from the tables constitute the lead product, which is said to average 57.5 per cent of lead, 10 per cent of zinc, and 40 ounces a ton of silver. The tailings that are waste in ordinary practice form in this mill the zinc product, with a content of 33 to 35 per cent of zinc, 6 to 8 per cent of lead, and 4 to 6 ounces a ton of silver. The mill is rated at 80 tons in 24 hours, but in actual practice three 8-hour shifts treat about 75 tons of crude ore daily.

This mill has been running for a little over a year on ore carrying from 16 to 17.5 per cent of lead, 27.8 to 29.8 per cent of zinc, and 11 to 11.7 ounces a ton of silver. The zinc is in the form of mixed smithsonite, calamine, and hydrozincite. The lead content is 75 per cent cerusite, the remainder being largely galena with some anglesite. The silver is almost entirely carried with the lead. Fred A. Hale, superintendent of the mine and mill, estimates that from ore of this class 68.6 per cent of the lead, 92.2 per cent of the zinc, and 62.6 per cent of the silver are saved. During the fall of 1912 the monthly shipments amounted to 1,500 tons of zinc tailings and 300 tons of lead concentrates.

A more detailed description of this mill has been prepared by the writer for publication in Mineral Resources of the United States for 1912.

TRANSPORTATION.

Hauling charges from the mines in the district to the shipping points, Arden, Jean, or Roach, are variable. The Potosi Mining Co. owns its own outfits and estimate that it costs 50 cents a ton to haul from the mine to Roach, a distance of 20 miles. On the other hand, lessees working in the vicinity of the Monte Cristo mine pay from $2.25 to $2.50 a ton to have their ore hauled to Jean, only 7 miles distant, and from the Milford and Addison mines to Roach, a distance of 16 miles, the usual charge is $6 a ton. It is fair to say that the average price for hauling is $2.50 a ton for the mines on the east side of the range and from $6 to $8 a ton for those on the Mesquite Valley side.

The Yellow Pine Mining Co. has built a 36-inch gage "ore road" from Jean to the Bybee mine, with switching facilities at the mill in Good Springs. A Shay geared locomotive is used to haul a train of seven 6-ton side-dump ore cars. Oil is used as fuel for this engine, the supply coming from the California oil fields at $1.24 a barrel f. o. b. Jean. The train makes two trips daily between the mine and mill and one trip to Jean with concentrates for shipment. The estimated cost for transportation is 45 cents a ton.

The freight charges from the shipping points to the smelters are fairly well established, being $6 a ton to the Salt Lake City plants and $8 a ton to the zinc smelters in the Mississippi Valley.

MINES.

MINES WEST OF THE MOUNTAINS.

POTOSI MINE.

The Potosi mine (No. 1, Pl. IV) was first worked for lead by the Mormons in 1860. The ruins of the original small lead smelter are still to be seen in the canyon northwest of the mine. The original location was the eighth claim, to which patent was issued by the United States and the deed was signed by President Lincoln. This property, which now consists of 28 claims and 6 mill sites on the west flank of Potosi Mountain, is controlled by Mahoney Bros., contractors, of Los Angeles, Cal.

The original development consisted of a tunnel on the ore about 600 feet in length. This tunnel is not now used. The main working tunnel is about 75 feet farther south and 25 feet lower. Its mouth is at an elevation of 6,400 feet, about 800 feet above the valley bottom. In the fall of 1912 it was approximately 1,200 feet long, running eastward into the ore body. There are three very irregular levels—65, 100, and 125 feet above the working level—which follow the ore bodies and are connected by numerous stopes, raises, and chutes, making a total of nearly three miles of workings. A vertical winze about 700 feet from the tunnel mouth is down 100 feet, and nearer the mouth of the tunnel there is an inclined winze on some ore. These workings are most irregular and it was unfortunate that the writer was not permitted to use the mine maps underground, for with their aid a much better idea of the relations of the ore bodies to one another and to the dislocations of the limestone might have been worked out.

The country rock is limestone. The mouth of the main tunnel is on a westward-facing north-south cliff, which seems to be due to erosion of the beds west of a fault. Figure 26 shows this general relation and the localization of the ore near the minor north-south faults.

The upper part of the cliff is composed of dark fine-grained massive limestones in beds as much as 6 feet thick. Some of the beds carry Carboniferous fossils which Mr. Girty regards as probably of upper Mississippian age. Chert is not abundant. A few of the limestones near the top of the cliff contain unequally distributed chert nodules, but in the ore-bearing limestone there is practically no chert. Immediately below this bed there are about 20 feet of hard, shaly limestones, of very dark color and fine grain, in beds 2 inches thick. The operators thought that these "shales," as they are locally called, formed the lower limit of the ore, but recent developments in the shaft indicate that some ore occurs also at a horizon at least 50 feet below them.

The sedimentary rocks, as shown by figure 26, are almost horizontal, though they dip slightly to the south and east, probably not over 5° to 10°. They are cut by two systems of crevices, one at right angles to the cliff face and one about parallel to it. The east-west crevices show no faulting, but along the north-south zone there has been movement. The east-west crevices dip to the south at medium angles, but the faults are essentially vertical like the main fault at the mouth of the tunnel.

The ore bodies are extremely irregular in size and detail but are without question clearly related to the fractures in limestone. The

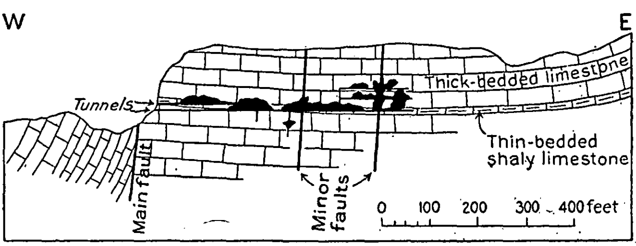


FIGURE 26.—Generalized cross section in Potosi mine, Clark County, Nev., showing relation of the ore (black) to minor faults and the position of beds on either side of the main fault.

waters which brought in the ores followed these more or less open courses and replaced the walls as well as partly filled the crevices.

The original character of the ore is indicated at one place on the 65-foot level above the main tunnel, where a small body of sulphide ore was found. This ore has not been developed but appears to be a remnant that has escaped oxidation. It consists of brown to black iron-bearing sphalerite contemporaneously intergrown with a little calcite and much less galena. Its borders are not sharp, the sulphide being irregularly altered to smithsonite. One specimen of this ore shows a fracture lined with small gypsum crystals.

The principal ore mined at the Potosi is a brownish-gray cellular smithsonite, but some of the zinc carbonate is well crystallized, particularly as linings in the cavities of the more massive ore. In a few stopes the zinc ore is an iron-stained sand. Here and there the typical white banded smithsonite is found lining cavities. Calamine is not abundant but is commonly present in the ore.

Intermixed with the zinc ore are large and small bodies of lead ore. The lead occurs commonly as pure cerusite, but also as galena, coated first with a thin layer of anglesite, outside of which is cerusite. The carbonate is dark gray, usually iron stained but showing the pearly luster characteristic of the mineral. There are a few fairly large stopes of nearly pure lead ore, but in general the lead ore is intermixed with the zinc ore and requires careful sorting.

Oxidized copper ores, largely cuprite, and a little malachite mixed with limonite are found, particularly along the north-south faults. There is evidence of movement since the formation of the carbonate zinc-lead ore bodies, but the copper ores have largely been deposited since the last movement.

The ore bodies vary from those a few feet in diameter to large masses. One of these completely blocked out is 150 by 60 feet in cross section and at least 100 feet high. Many of the stopes are 8 to 12 feet wide. Both underhand and overhand stoping are practiced, and almost no timber is used in the mine. The ore so far shipped has been taken from the tunnel level or above. It is hand sorted into two products, one largely lead and the other zinc. From the bins at the tunnel mouth the ore is carried by an 1800-foot gravity tram to the main road in Potosi Wash. At present the production is about 700 tons of sorted zinc ore a month, which runs 34 to 48 per cent of zinc and 2 to 5 per cent of lead. Besides the zinc, a considerable amount of crude sorted lead ore is sold, which is said to run 65 to 70 per cent of lead, 6 to 7 per cent of zinc, and 15 to 16 ounces a ton of silver.

GREEN MONSTER MINE.

The Green Monster mine (No. 2, Pl. IV) is in the northwestern part of the Yellow Pine district, at the west end of the long east-west spur that partly separates the Mesquite and Pahrump valleys. The mine is the property of the Hearst estate and for several years, before the discovery of the zinc ores, was a producer of lead and silver. It had been closed for some time prior to 1912 and the workings were not accessible. There are two inclines on the north lower ore body, in which considerable work has been done, and a vertical shaft sunk south of the outcrop is said to be about 300 feet deep. There was no ore on the dump of this shaft, so it seems probable that the ore zone has not yet been cut. There are two ore bodies 4 to 6 feet wide in the 40 feet of grayish-white crystalline limestone immediately below very dark fine-grained cherty fossiliferous limestones. These are parallel to the bedding of the formations, which strike N. 40° W. and dip 65° SW. A few imperfect fossils collected here are determined as probably upper Mississippian.

The outcrops consist of yellow to brown cellular earthy material showing in a few places small remnants of galena. This capping is largely limonite but contains some lead and zinc, in the form of carbonates. In some surface stopes there are still masses of grayish, yellow-stained cerusite, incrusting galena. Anglesite occurs in places as a coating between the carbonate and sulphide.

There is considerable zinc carbonate on the dump and some is visible in the open cuts. This mineral occurs both in gray-white massive and banded form and in brownish iron-stained masses. Hydrozincite coats some of the smithsonite. Calamine is, to judge from the dump, scarce but was seen as laminæ in the banded carbonate ore.

So far as could be determined the ore is localized along more or less open cavities. Some postmineral movement has taken place along these zones.

KEYSTONE MINE.

The Keystone mine (No. 3, Pl. IV) is on the west side of Spring Mountain about 2 miles southwest of Shenandoah Peak, 5 miles northeast of Sandy, and 8 miles west of Good Springs. A large group of claims is controlled by the Nevada Keystone Mining Co., but the mines have been idle since 1906. Previous to that time the Keystone was worked intermittently for about 15 years and is reported to have produced $1,000,000 in gold.

The development consists of several large open-cut glory holes, three tunnel levels, and an inclined winze from the lower working tunnel, said to be 1,100 feet deep. From the lower tunnel there are a number of crosscuts and raises to the upper levels. The workings were badly caved in September, 1912, and but little of the deposit could be seen.

The limestones of the north side of the east-west ridge on which the Keystone is located dip 30° SW. near the mine but are nearly flat at the top of the hill south of the tunnels. North of the canyon in which the mine is located there is a small area of pinkish-gray limestone which appears to be a downfaulted portion of the lower Pennsylvanian similar to the limestones in the low hill north of Good Springs. The limestones in which the mine is located are blue-gray dense rocks. They are cut in a most irregular way by dikes and sills of quartz monzonite porphyry which have a general north-south elongation. The porphyry is not exposed north of Keystone Canyon but is said to extend southward almost to the Good Springs and Sandy road. At the hoist station in the lower tunnel the intrusion varies from 70 feet to 4 feet in width in a distance of 50 feet. The limestone for 2 inches from the contact is usually somewhat bleached, silicified, and cut by little stringers of quartz; other than this there is no contact alteration.

The porphyry is much altered in all places where it was seen, though usually its original texture can be determined. The minerals formed appear to be limonite, chlorite (?), sericite, and kaolin. In one specimen cubes of hydrated iron oxide, evidently an alteration product of pyrite, were noted. This altered porphyry is the ore and its value is due entirely to free gold, which occurs in minute flakes throughout the ore, especially where the rock is most iron stained.

The tunnel could be entered for only 450 feet. It runs S. 5°–20° W. along a series of overlapping branching faults which cut both porphyry and limestone, though very commonly the movement has been at the contacts of these two rocks. These faults run into and away from one another, though all of them dip to the west, some steeply and others at low angles. There is usually from 1 to 2 inches of hard dry gouge along them, but no dominant direction of movement could be ascertained.

It is said that the smaller sills and dikelets were usually richer than the larger bodies of porphyry, which appears entirely plausible, for the big masses of quartz monzonite are usually less altered than the small ones.

The ore was all raised or dropped to the lower-tunnel level, trammed to bins on the dump, and drawn into the wagons which took it to the cyanide mill at Sandy, the nearest water. The grade of the ore is not definitely known but is thought to have been between $18 and $25 a ton in gold and a little silver.

AURA AMIGO CLAIMS.

The Aura Amigo claims (No. 4, Pl. IV) are in a small canyon south of Keystone Canyon, about 2 miles west-northwest of the Keystone mine. In 1912 they were being worked by Eggler White and C. M. Overs, the owners. The deepest working is an inclined shaft, about 30 feet under cover, and there are several other pits and open cuts over a length of two claims.

The dark gray-blue limestones, which dip to the southwest at medium angles, are here cut by a fracture that strikes N. 60° E. and dips 60° S. The ore makes along this fracture, varying from a few inches to a foot in width. The largest body seen is at the junction with a N. 30° W. vertical crevice, where there is 10 feet of ore. The ore is largely limonite with some "copper pitch ore," malachite, and chrysocolla. In a crevice in the carbonate ore there was found a thin olive-green coating, which proved to be copper phosphate.

WHALE GROUP.

The Whale group (No. 5, Pl. IV), comprising two claims, belongs to Miller & Tursick, of Good Springs. These claims are located in the hills north of the Good Springs and Sandy road, about 4 miles east of Sandy.

The principal development work is a 75-foot incline on the south side of a steep draw, at an elevation of 4,000 feet.

The ore occurs in buff-gray, somewhat crystalline limestone, immediately over a bed of blue cherty limestones, and has been traced by open cuts for about 1,800 feet. The beds strike N. 40° E. and dip 75° SE., and the ore is in the same position.

The body in the shaft is along a more or less open watercourse and varies from 2 to 12 feet in width. The ore is all iron-stained smithsonite, with a very minor amount of hydrozincite. On some drusy surfaces there are grayish crystals of calamine.

BILL NYE MINE.

The Bill Nye mine (No. 6, Pl. IV) is just south of the Good Springs and Sandy road, on the west side of the summit, at an elevation of 3,950 feet. The property belongs to John Allen and William Frederickson, of Good Springs.

A crosscut tunnel, 200 feet long, with one short drift, is the principal development work. This tunnel is run eastward through thin-bedded buff-gray limestones that locally strike N. 30° E. and dip 45° SE. The beds are cut by a vertical fault striking N. 80° E., along which the nearly horizontal movement has formed a breccia from 10 to 12 feet wide. In this breccia there are small pockets of mixed lead-zinc carbonate ores. On the surface of the hill, in irregular pockets along the bedding planes of the limestone, there seems to be more ore than at the depth of the tunnel.

HOODOO MINE.

The Hoodoo mine (No. 7, Pl. IV) is located about a mile south of the Good Springs and Sandy road, 3 miles east-southeast of Sandy. It is in a pocket in a group of low hills entirely surrounded by wash material. There are three claims in the group, belonging to the Kansas-Nevada Mining Co.

The ground is developed by a 600-foot crosscut tunnel running almost due east into the hill, from which there are four short drifts on ore.

The country rock in this vicinity is a grayish-white crystalline limestone. It is cut by an east-west vertical fault zone marked by about 200 feet of calcite-cemented limestone breccia. The sedimentary rocks on both sides of the fault dip to the north at low angles.

The ore bodies are all in the zone of brecciated limestone and are localized along later north-south planes of movement that are vertical or have a steep dip either to the east or west. The movement along them has been slight but has left the fractures more or less open.

The ore is largely white smithsonite with some hydrozincite and a minor amount of calamine. It occurs as crusts lining the open watercourses, as fairly large replacement masses adjacent to the fissures, and as a cementing material of the breccia near the main masses. At the mouth of the tunnel a body of iron-stained zinc carbonate contains small masses of lead carbonate and anglesite surrounding kernels of galena.

This mine is reported to have shipped a few carloads of sorted zinc and lead ore, but figures as to its total production are not available.

TIFFIN AND SINGER MINES.

The Tiffin and Singer claims (No. 8, Pl. IV) are on the south side of a group of isolated hills 5 miles southeast of Sandy. The Tiffin is owned by C. Beck, of Good Springs, and the Singer by Judge Ross, of Los Angeles, Cal. They are both developed by short tunnels and open cuts and are reported to have shipped only a small amount of ore.

The country rock is buff-gray limestone that in this hill dips 30°–40° SE. The up-tilted limestones are cut by small north-south fractures, along which the ore occurs.

At the Tiffin a N. 20° W. fracture has been followed for about 200 feet, with several crosscut drifts, making a total of 300 feet of work. Two raises 50 and 40 feet in height have been driven, the higher one connecting with an open cut on the surface. Along this fracture there is from 6 inches to 1 foot of mixed zinc and lead carbonate ore with a little galena. In some of the ore, especially along recent planes of movement, there were found small yellowish crystals which were said to be an uranium-bearing mineral but prove to be pyromorphite.

The Singer mine has a 50-foot tunnel run along the west side of a vertical fracture that strikes N. 10° E. In the buff-gray limestone adjacent to the fissure there are some irregular bodies of galena, now largely altered to anglesite and cerusite. Pyromorphite coats cerusite in a few specimens. Zinc minerals are absent from the ore as far as seen.

HOOSIER MINE.

The Hoosier mine (No. 9, Pl. IV) is located at the west base of Table Mountain, about 5 miles in an air line southwest of Good Springs. The two claims in this group belong to Harry Joseph, of Salt Lake City. The development work is located on both sides of the canyon, near the wash, in a buff-colored crystalline limestone that dips about 5° W. Most of this work consists of pits, open cuts, and short tunnels. The main working on the north side of the canyon, at an elevation of 4,000 feet, consists of an irregular tunnel, about 300 feet long, with two mouths, the western being 15 feet below and 200 feet distant from the eastern entrance. From this tunnel there are several small flat stopes.

The ore occurs in irregular pockets, some of them 5 feet in thickness, in buff, upper Mississippian limestone. These pockets follow the bedding planes in general, but expand into the limestone in irregular kidney form. The small ore bodies are found over a vertical range of 50 feet and for about 1,500 feet east and west and 400 feet north and south.

The ore is largely smithsonite, galena, and cerusite, with minor amounts of anglesite and calamine. The lead and zinc minerals are very closely associated, and for this reason the deposit can hardly be worked unless the ore is milled.

MILFORD MINE.

The Milford mine (No. 10, Pl. IV) is on the west side of the mountains, near the south end of the district, about 2 miles southwest of Little Devil Peak. The group of five locations is owned by the Good Springs Mining Co., but in the fall of 1912 was under bond and lease to H. J. Jarman and associates.

The mine is developed by an irregular tunnel about 200 feet long that is largely in the hanging wall and by several open cuts on the surface. In September, 1912, an inclined shaft in the hanging-wall ore was 80 feet deep, with short, irregular drifts and stopes at four levels. The ore zone is clearly traceable for about 300 feet east of the main workings by croppings of galena and lead-carbonate stains.

The country rock is all limestone; the beds strike approximately east and west and dip 75°–80° S. The footwall of the ore is a massive bed of dark-gray, almost black, cherty fossiliferous limestone of probable upper Mississippian age. The ore is found in a bed of finely crystalline gray-blue limestone for 40 feet above the dark bed. This limestone is cut by numerous watercourses which are about parallel to the position of the beds and along which the ore has developed. The hanging wall of the ore zone is a massive buff-gray limestone, below which a crevice conformable with the dip is filled with reddish-brown sandy carbonate ore containing both lead and zinc. Below the hanging-wall ore there are numerous rather large irregular pockets of white zinc carbonate. The smithsonite usually occurs in massive or banded form, but in some druses in this ore small crystals of the carbonate are seen. Calamine is present in relatively small quantities, but is seen in the banded ore and in some crusts in druses. Mixed with the zinc is a small amount of lead ore, consisting of kernels of galena coated with anglesite, outside of which there is lead carbonate. The lead ore is easily sorted from the zinc and constitutes less than 5 per cent of the product. The zinc ore is said to average 45 per cent of zinc and 6 per cent of lead.

ADDISON MINE.

The Addison mine (No. 11, Pl. IV), 1 mile southeast of the Milford, belongs to the same company. There are four locations in this group which are under lease to H. J. Jarman and associates.

The main ore body is in the low hills just east of the Mesquite Valley Wash. It is developed through a vertical range of 158 feet by open cuts, a 150-foot tunnel, and an 88-foot winze, from which there is a short drift 64 feet below the tunnel level.

The country rock is largely the buff-gray limestone characteristic of the ridge between the Milford and Addison mines, but at the Addison mine the hanging wall of the ore zone is a 20-foot bed of dark-blue limestone. The beds strike approximately east and west and dip south at medium angles. They are cut by two open crevices. One strikes N. 55°–60° E. and dips 75° N.; the other is a vertical north-south fracture along which there has been a little movement.

The ore is localized near these fractures, and the largest body occurs at their junction. There are also some irregular replacement bodies parallel to the bedding of the limestone just southeast of and above the main ore body, below the dark-blue limestone.

The ore is fairly pure white smithsonite and hydrozincite, in places stained by limonite. Calamine is very subordinate. Above the tunnel level kernels of galena, surrounded by anglesite and cerusite, are found.

OTHER MINES ON THE WEST SIDE OF THE MOUNTAINS.

Time did not permit visiting several mines and prospects in scattered localities on the west side of Spring Mountain. Several of these properties have been producers. The Azurite, Boss, Shenandoah, and Mobile are on the ridge about 3 miles northeast of Sandy, and the Bonanza is about 5 miles southeast of the same place, on the north side of the hills north of the cut-off road from Knights Well to Good Springs. The May-Kirby group is on the south side of the ridge about 1½ miles southeast of the Keystone. It is said that a large amount of manganese occurs with the zinc carbonate ore at this place. The Ingomar is near the top of the ridge between the Addison and Milford. High-grade galena and cerusite ore was shipped in 1912 from this property by D. W. Johnson.

The Volcano and Frederick Ward, both being worked in the fall of 1912, are near the top of Table Mountain, about 1½ miles south of

Summit, on the Good Springs and Sandy road. From these two properties both crude lead and crude zinc ore of good grade were being shipped.

MINES EAST OF THE MOUNTAINS.

NINETY-NINE MINE.

The Ninety-nine mine (No. 12, Pl. IV) was located in 1899 by a Mr. Over, of Good Springs, and passed into the hands of the present owner, J. B. Jensen, in the spring of 1907. There are nine adjoining claims in the group, on the lower part of the east slope of Potosi Mountain.

The principal development is a 400-foot shaft in the northeastern part of the group, at an elevation of 5,500 feet. The shaft is vertical for the first 150 feet, below which it dips 75°–80° N. It is equipped with a 15-horsepower gasoline hoist and buckets. There are short drifts at the 100, 150, 200, 250, 300, and 400 foot levels, none of which are over 200 feet in length.

The country rock is the blue limestone of the upper Mississippian (?) section, with some fossiliferous beds southwest of the shaft interbedded with coarsely crystalline limestone. These beds strike N. 25° W. and dip 45°–50° NE. in the vicinity of the shaft.

The beds are cut by a fault zone which strikes N. 65°–70° E. It dips 87° N. to a depth of 150 feet, but flattens to 65° at the 200-foot level and to 45° at the 250-foot level. At the 300-foot level the dip increases to 75° and striæ on the footwall pitch 15° E. This fault zone is filled with 2 to 4 feet of crushed limestone, in places partly cemented by calcite. The fragments are all under 1 inch in size and the great majority less than half an inch. Above the 250-foot level this filling is more or less iron-stained and contains pockets and stringers of copper carbonates and oxide constituting the ore. On the 250-foot level, from 30 to 70 feet east of the shaft, there is an open stope 4 to 6 feet wide which extends to the 200-foot level and from which a considerable body of ore was taken. In some of this ore there are small remnants of chalcocite, now largely altered to cuprite and malachite. At the 200-foot level the limestone for 8 feet north of the fault contains some limonite, which fades out into unaltered limestone at a distance of 10 feet. At one place near the east end of this level there is a flat stope where the ore is apparently conformable to the bedding of the limestone. At the 400-foot level the fault zone is still strong, but shows no mineralization.

All the ore from this mine was taken from the surface to a depth of 260 feet, where it played out, from stopes running not over 80 feet east of the shaft. The ore is sorted at the mine, and of 25 cars shipped in the fall of 1912 none ran below 20 per cent of copper, and most of it averaged 24 to 25 per cent.

CONTACT GROUP.

Five claims belonging to A. L. Chaffin (No. 13, Pl. IV) are located along the great fault about 2½ miles south of the Ninety-nine mine and 7 miles north-northwest of Good Springs. There are a number of open cuts and shallow shafts located west of the fault zone on small ore bodies and a few cuts in the fault zone itself.

All the ore is found in the Mississippian(?) limestones, none occurring in the red Triassic (?) sandstones. At several of the prospect holes there are small bodies of zinc or zinc-lead carbonate ore. The largest body seen was in an inclined shaft 400 feet west of the fault along an open watercourse that dipped 25° E. The ore here is from 1 to 2 feet thick and has been opened for a distance of 30 feet.

In some pits in the great fault zone there are small deposits of copper carbonate ores.

NINETY-THREE GROUP.

Richard Feaster, of Good Springs, has a group of eight locations (No. 14, Pl. IV) in the low hills about 2 miles north of the Bybee mine. The deepest working is an 80-foot shaft near the center of the group, though there are several shafts from 10 to 25 feet deep and numerous open cuts and pits.

The blue-gray limestones at this locality strike N. 20° E. and dip to the west at low angles. Along the center of the south end of the group there is a dike of quartz monzonite porphyry similar to the rock at the Red Cloud and Bybee mines. At one place this dike is 200 feet wide. It is traceable northward by poor discontinuous exposures for about 1,000 feet. The limestones are cut by a series of north-south fractures of apparently slight throw along which there has been some mineralization. In a few of the pits the ores are largely copper oxide and carbonates; in others lead and zinc carbonates are seen. There are a number of fairly good surface showings of both classes of ore on these claims, but no workable bodies have been demonstrated.

In one shaft near the south end of the group and 400 feet west of the porphyry dike there is a 1-foot bed of light-gray barite, near the top of the shaft. The barite is clearly an alteration product of the limestone, as there is still a small amount of calcium carbonate in the rock, though it appears on casual inspection to be entirely the barium sulphate.

RED CLOUD MINE.

The Red Cloud mine (No. 15, Pl. IV) is on the north side of the Good Springs and Keystone road about 2 miles north of the Bybee mine. This mine, the property of Joseph Armstrong and John Loup, was not operated in the fall of 1912.

A single-compartment shaft, said to be 300 feet deep, could be entered only as far as the 100-foot level. It is vertical to this depth, but pitches about 70° NE. a short distance below the station. The drifts on the first level extend about 70 feet northwest and 120 feet southeast of the shaft. About 100 feet southeast of the shaft there are two open stopes 5 to 8 feet wide, 40 feet long, and 20 and 50 feet in height. As almost no timber has been used in the mine it is caving badly.

The shaft is sunk in very soft altered granite porphyry near its southwest contact with gray limestone beds that dip 35°–45° SW. The dike is about 100 feet in maximum width and strikes N. 45° E. on the surface. Underground the contact shows some silicification of the limestone but no other alteration. A zone of crushed limestone and porphyry follows the contact, striking N. 20°–60° W.

The ore is the soft altered iron-stained porphyry near the contact. It is said to carry from $15 to $60 in gold to the ton, the lower figure being nearer the average content. Cinnabar is said to have been seen in some specimens from this mine, but none was observed during this reconnaissance.

PRAIRIE FLOWER MINE.

The Prairie Flower mine (No. 16, Pl. IV) is about half a mile north of the Bybee mine in the same canyon. The shaft is on the west side of a low ridge that separates Yellow Pine Wash from a western arm of the large wash between Spring Mountain and the Bird Spring Range. This mine is controlled by the Knight-Hyde interests but in 1912 was under lease to George Meacham.

It is developed by an inclined shaft which was about 225 feet deep in September, 1912. The shaft dips on an average 60° NW. It is equipped with a gasoline hoist, a 1-ton bucket being used for raising the ore. At the 50-foot and 100-foot levels there are drifts south on the ore, and large open stopes from 5 to 15 feet in width are carried to the surface for a length of about 70 feet.

The limestones in this vicinity have a gentle southwesterly dip and are cut about 50 feet west of the shaft by granite porphyry. On the surface the contact is covered by wash, but at the 100-foot level a crosscut 70 feet south of the shaft shows the contact. It is nearly vertical and very sharp, and the limestones show no alteration except a slight silicification.

The ore occurs along an open watercourse in the limestone about 15 feet east of the porphyry, striking N. 45° E. and dipping steeply northwest. The shaft appears to be over the main crevice below the 100-foot level, on a branch that is not so strongly mineralized. The ore is an iron-stained mixture of lead and zinc carbonate, the latter predominating, in which there are some small masses of hydrozincite and some kernels of unaltered galena.

BYBEE MINE.

The Yellow Pine Mining Co., the largest producer in the Yellow Pine district, is operating the Bybee mine (No. 17, Pl. IV), 4 miles west of Good Springs. This company owns 14 claims in the district, the largest group being about the Bybee mine and several others on which some prospect work has been done being in the vicinity of the Monte Cristo mine.

The Bybee is developed by a shaft that is 166 feet deep on the incline, which is 49° to the first level and 35° below that. From the shaft there are levels at 82, 110, and 134 feet. There are approximately 680 feet of drifts on the first level, 966 feet on the second, and 342 feet on the third. Between the first and second levels southwest of the shaft there is an intermediate level and series of stopes about 160 feet long. From the third level 156 feet southwest of the shaft there is an inclined winze dipping 55° W. that is 210 feet deep measured on the incline, from which there are three levels at 86, 130, and 182 feet below the third level. In these levels there are short drifts to the south in the ore zone. Figure 27 shows the intricacy of the levels and connections.

A 15-horsepower gas hoist operates the 1-ton skip in the main incline, and a 25-horsepower engine runs the compressor and a 12½-kilowatt generator. Electricity is used to light the mine and for hoisting in the winze below the third level.

The blue-gray, somewhat crystalline limestones of upper Mississippian (?) age in the vicinity of the Bybee mine dip 30°-45° WSW. They are intruded by granite porphyry. On the surface the east porphyry and limestone contact is 100 feet west of the shaft and the porphyry mass is 400 feet wide. The igneous rock is not clearly shown on the surface, owing to the covering of wash material, nor is it exposed underground at any place in the mine. It seems from these facts that the intrusion is either in the form of a sill or that it is a very flat-lying dike. Two faults which cut both the limestone and porphyry strike about N. 60° W. and on the surface appear to dip 70°-80° S. Along both of these faults the south side seems to have dropped from 10 to 20 feet with reference to the north side. Underground the southern fault is more clearly marked than the northern one. The direction and dip of the southern fault are seen to vary considerably at the few places underground where the wall is distinctly shown.

The ore bodies so far opened are entirely between the two fault zones. It has not been demonstrated, however, whether or not there is ore beyond them.

The ore body in the upper three levels dips about 30° W. and the lower limit of ore pitches about 15° SW. The first level is in ore for its entire length north of the shaft and for at least 190 feet south of it, but at this distance the ore is largely in the lower part of the drift. At the intermediate level the northern limit of ore is about under the shaft, but at the second level it is 120 feet south of the shaft, and at the third level the drifts are all in barren ground to a point 135 feet south of the shaft. (See fig. 27.) This ore body

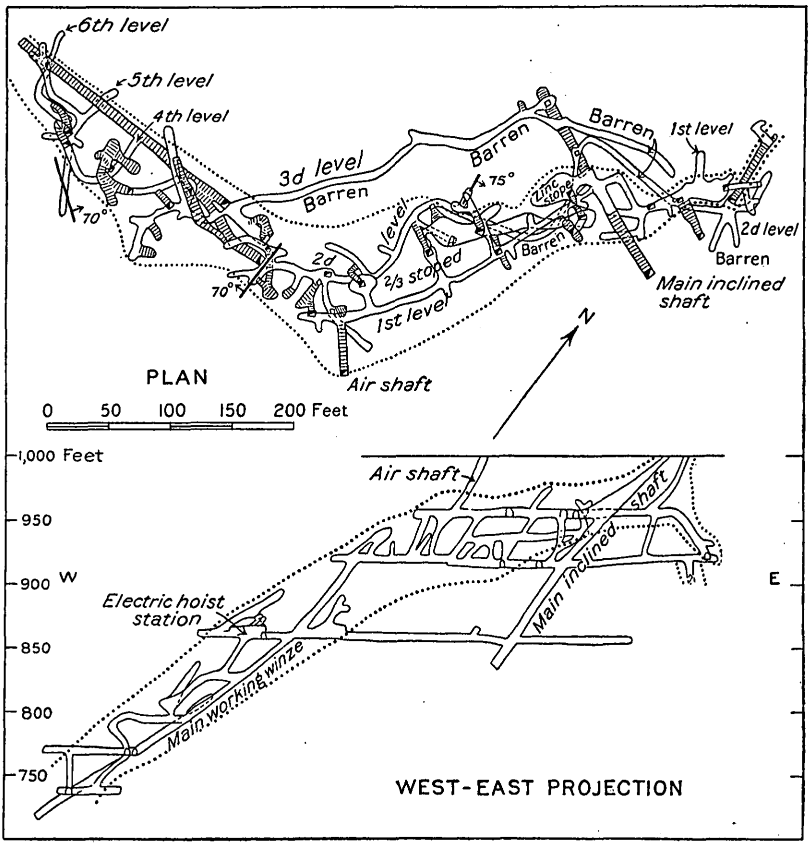


FIGURE 27.—Plan and elevation of the workings of the Bybee mine, Clark County, Nev.

is from 50 to 70 feet wide, about 360 feet long, and from 30 feet thick at the north end to about 60 feet thick at the south end. The north end gives the effect of wedging out, but it is cut off by a rather indistinct zone of brecciation that seems to represent the northern fault seen on the surface northwest of the shaft. The south end is clearly faulted. Near the face of the main drift on the first level (see fig. 27) there is a 30-foot zone of brecciated limestone and ore that is partly cemented by calcite, in which there is some calamine.

The winzes between the first and third levels shown at the left side of figure 27 are in or near this fault zone. Between the second and third levels near the fault the ore body is 77 feet wide and the ore is continuous for a distance of at least 30 feet north of the fault.

The main working winze below the third level is started north of the fault zone and the ore is found to the south of it near the brecciated area. A small open watercourse which cuts across the winze at the 600-foot level strikes N. 35° E. and dips 75° SW. This seems to be a branch from the main fault, though as yet developments are not extensive enough to determine the point.

The winze from the north end of the second level is entirely in ore that appears to be in the form of a chimney along the north fault zone.

The ores so far mined consist largely of an iron-stained mixture of smithsonite, cerusite, and galena, in which there is more or less anglesite, calamine, and hydrozincite. The latter two minerals occur as fillings of open watercourses. Calamine is found here and there as crystalline crusts in the very recent opening. Hydrozincite occurs as irregular masses in the other ore. The large stope on the first level just south of the shaft (see fig. 27) was entirely in hydrozincite. This was a remarkably large body, as the mineral occurs most commonly in masses from a few inches to 4 feet in diameter. Anglesite is seen only as thin crusts surrounding crystals of galena. Galena is found throughout all the ore, but is much more abundant above the third level than below it. Cerusite is found in sandy form mixed with the zinc carbonate and at the north stope on the first level as ribs of solid gray mineral in the smithsonite. The zinc carbonate from the Bybee is practically all iron stained and rather sandy, though both the massive and the banded forms are found.

The walls of the ore bodies are in most places sharp but very irregular in detail. The zone of transition from good ore to barren limestone is everywhere less than 2 feet wide, and usually the line separating ore and waste can be noted with exactness.

It is thought that there was movement along the faults at the ends of the ore body previous to the deposition of the carbonate ores as well as after that time. This conclusion was reached because of the presence of fragments of limestone in a matrix of smithsonite in the breccia caused by the postmineral movement.

It is understood that in the fall of 1912 the monthly production of this mine was 1,500 tons of zinc concentrate, 300 tons of lead concentrate, and 150 tons of crude ore.

The mine is well timbered, the square-set system being used; each set is 7 feet square. All the timber used is Oregon or Washington pine.

ALICE MINE.

The Alice group of 11 claims (No. 18, Pl. IV) covers the ridge a quarter of a mile south of the Bybee. The group belong to A. J. Robbins, of Good Springs. The main development work is a 375-foot incline which bears S. 30° W. and dips into the hill at an average of 20°. From this incline there are short drifts and irregular stopes on ore bodies.

The gray limestones of this ridge strike northwest and southeast and dip 30°–40° SW. They are cut by a dike of coarsely crystalline-granite porphyry which ranges from 2 to 40 feet in width and whose outline is very irregular. This dike appears on the surface only as high as the tunnel mouth and seems to come up along a vent striking N. 40° E. It is exposed in the low saddle from which the incline starts, but west of this place the intrusive rock turns down along the bedding of the limestones as a sill from 4 to 20 feet thick. The contacts are very sharp, but in most places are marked by crushed zones. The limestone is broken into angular blocks 1 to 2 inches in size for a width of 20 feet and is slightly silicified immediately at the contact. The porphyry shows only slight crushing.

The ore bodies extend along the bedding planes of the limestone both above and below the porphyry sill. They range from 2 to 5 feet in thickness and are of various sizes, from a few cubic feet to as much as 200 cubic feet.

The ore is all much iron-stained and in places carries an appreciable amount of oxidized copper ore. In some stopes the zinc minerals smithsonite, hydrozincite, and calamine are intimately mixed, the smithsonite being in excess. In other stopes, both near the surface and to the greatest depth attained, galena, cerusite, and pyromorphite are seen mixed with the zinc minerals.

This mine is a steady producer of sorted crude ore, but the present development has not demonstrated any very large bodies.

PORPHYRY CANYON CLAIMS.

There are several claims in what is called Porphyry Canyon (No. 19, Pl. IV), a small gulch about half a mile east of the Bybee mine. These claims, the Copper Glance and Middlesex group, belong to the Campbell estate, which is said to control a large number of isolated claims in various parts of the district.

The dark-gray limestones in this gulch dip southwest into the hill east of the Bybee and are cut by granite porphyry in at least two places. The igneous rocks appear to be dikes that have not reached the top of the ridge surrounding the gulch. There are several minor fracture planes cutting the limestone. One near the mouth of the canyon on the west side has an east-west direction, though on the east and south sides fractures with a north-south direction are most commonly seen.

The Copper Glance claim is on the east-west fracture, along which the limestones are shattered for a width of 2 to 3 feet and are somewhat impregnated with red copper oxide and limonite. Films of chrysocolla and malachite coat the fragments and in some specimens penetrate the red ore.

Near the head of the canyon on the west side there are some open cuts and shallow tunnels on a bedded deposit of smithsonite carrying a little lead.

At the east head of the gulch there is about 150 feet of tunnel work on a steeply westward-dipping open crevice, along which some rich argentiferous lead carbonate ore was found, but the ore bodies are small and discontinuous.

Along the east wall of the canyon there is a north-south zone in which at several places small bodies of copper carbonate ores were found. This is traced for about 800 feet by shallow pits and cuts.

LAVINA MINE.

The Lavina claims (No. 20, Pl. IV) lie along the great fault west of Good Springs. There are a large number of claims in the group which belong to Harvey Hardy & Co., of Good Springs. The Lavina shaft is on the southeast side of the hill, southeast of the Bybee mine. It is said to be 170 feet deep, but was not entered. It is sunk in highly altered, somewhat crushed granite porphyry about 120 feet east of the great fault. From the collar of the shaft there is a 150-foot tunnel running westward into the hill. The gray limestones of upper Mississippian (?) age west of the fault dip to the west-southwest at medium angles. East of the fault the light-colored grayish to pinkish Pennsylvanian limestones and conglomerates dip steeply to the west. The fault zone is at least 50 feet wide, as shown by the Lavina tunnel, which, however, does not penetrate the blue-gray limestones. Just east of the face of the tunnel is 15 feet of a fine breccia, in which there are fragments of the dark limestones. East of this belt there is 35 feet of iron-stained sandy clay gouge which grades into the altered porphyry. The line of demarcation between gouge and porphyry is not sharp; in fact, it can not be definitely stated where one begins and the other ends. In this zone and in the altered porphyry there are irregular bodies and stringers of dark ore. It consists of aggregates of quartz, calcite, and cupriferous pyrite that are crushed and recemented by quartz and pyrite. This ore is said to carry about $10 a ton in free gold. About 1,000 feet east of this shaft small dikes of porphyry cut the Pennsylvanian limestone, and along some of them there are limonitic copper-stained cellular ores that are said to carry a little gold.

COLUMBIA MINE.

The Columbia group of six claims (No. 21, Pl. IV), just south of the Good Springs and Sandy road, about 3 miles west-southwest of Good Springs, is owned by a company headed by Joseph Deidrich, of Los Angeles, Cal. The main development, consisting of five inclines and two tunnels, is near the west center of the group, about half a mile east of the summit and a quarter of a mile south of the main road. These inclines vary from 20 to 200 feet or more in depth and are all located in the same ore horizon. From most of them there are small, irregular stopes. The two tunnels are below the ore zone and were apparently used for transportation.

The limestone at this locality is buff-gray to pinkish gray in color, and in general the formations strike east and west and dip 10°–20° S. The ore occurs in a pinkish crystalline limestone immediately below a bedding plane along which there has been slight movement that has produced from half an inch to 1½ inches of gouge. This movement was subsequent to the formation of a series of north-south vertical fractures, and it is along or near the junction of the two sets that the largest ore bodies are found.

The ore, all of which is oxidized, occurs as irregular though more or less tabular masses, roughly conformable with the bedding of the limestone, and is usually associated with coarse crystals of calcite stained pink or green by iron or copper. The ore minerals are limonite, cuprite, and malachite, with minor amounts of chrysocolla and azurite. In the western incline the pink limestone for about 10 feet below the main flat fracture is speckled with small black areas that were considered to be ore but that have proved to be only iron-stained calcite.

Below a depth of 70 feet most of these inclines show very little if any mineralization of the limestone, though the fractures unquestionably continue. Whether other ore bodies occur at a lower level is not known.

FREDERICKSON MINE.

The Frederickson mine (No. 22, Pl. IV), belonging to William Frederickson, of Good Springs, is located about 400 feet south of the summit on the Good Springs and Sandy road. The mine is developed by a 100-foot drift tunnel and inclined shaft on the ore, said to be 160 feet deep. The country rock is all limestone, and a particular bed of somewhat sandy greenish-buff limestone forms the hanging wall of the ore throughout.

Immediately below the hanging wall there is a fairly regular bed of ore 1 foot thick, and below this, at several places, lie irregular bodies of various sizes. The ore at the surface is a mixture of lead and zinc carbonate, with some galena, but at the tunnel level, at a depth of 30 feet, there is very little lead, the ore consisting of massive smithsonite with some hydrozincite. In the hanging-wall streak there is a slight development of calamine as crystals in small druses.

The ore so far shipped has been taken out largely above the tunnel level and near its mouth. It is all hand sorted into lead and zinc products.

MONARCH GROUP.

The Monarch Group of claims (No. 23, Pl. IV), just south of Crystal Pass, about 1½ miles north of the Lincoln mine, belongs to C. M. Overs, of Good Springs. The development work on this group consists of three short tunnels and several shallow shafts.

The thin-bedded blue limestones in this vicinity as a rule dip to the west-southwest at medium to low angles but exhibit some folding. They are cut by small, irregular dikes and sills of quartz monzonite porphyry.

The ore found along the contacts is auriferous limonite, which is an alteration product of magnetite. It is from 1 to 6 inches in width and is said to carry from $5 to $10 a ton in gold, with a little silver.

LINCOLN MINE.

The Lincoln mine (No. 24, Pl. IV) is at the edge of the Ivanpah Valley about 6 miles west of Jean and 4 miles south of Good Springs. The mine was originally worked by a shallow shaft, but the latest development is an incline 170 feet in length that runs N. 30° W. on a dip of 12°–15°. The limestones of the locality dip about 15° WSW. The incline follows an open crevice along which the grayish limestone is rather coarsely crystalline. In this calcite near the fracture there are a few small, irregular masses and stringers of copper ore. From the surface to a depth of 15 feet there was about 6 to 8 feet of ore. The ore is a brownish-red earthy mixture of limonite and cuprite, with some chrysocolla and malachite and locally a little azurite.

PORTER GROUP.

The Porter group of four claims (No. 25, Pl. IV) is the property of the Yellow Pine Mining Co. The claims lie along eastward-facing cliffs at elevations ranging from 3,800 to 4,000 feet, south and west of the Monte Cristo mine.

There are a number of open cuts and pits on the claims south of Monte Cristo Gulch, but the principal development is on the Porter claim, about half a mile northwest of the Monte Cristo, on the north side of the canyon. At this place there are two short tunnels, about

80 feet apart, running north into the cliffs, that are connected by a drift which starts near the entrance of the west tunnel and enters the east tunnel about 25 feet from its mouth.

The bluish limestones of this vicinity have a very low dip to the west and at the mine are cut by an east-west crevice along which they are altered to white calcite. The ore, practically all galena with films of anglesite on the surface, is intergrown with the calcite, but is also found to a very minor extent in the relatively unaltered blue limestone for several feet from the crevice. At the face of the east tunnel, about 30 feet north of the fracture, the limestone appears to be unaltered.

A winze sunk from the drift about halfway between the two tunnels is on the crevice, which is here filled with a limonitic sand carrying cerusite and some small masses of galena.

The largest ore body is exposed in the mouth of the east tunnel south of the crevice, where coarse galena is intergrown with large crystals of milky-white calcite. This irregular mass, about 6 by 10 feet in cross section, has been stoped for a height of 12 feet.

MONTE CRISTO MINE.

The Monte Cristo group of eight claims (No. 26, Pl. IV) is in Monte Cristo Canyon, about 6 miles south of Good Springs and 7 miles southwest of Jean. Owing to some internal trouble the Monte Cristo Consolidated Mines Co., of Los Angeles, Cal., has not operated the mine during the last few years, but in 1912 John Frederickson, of Good Springs, had the property under lease.

The mine is developed by large open cuts, a tunnel about 150 feet long, chiefly under the ore, and a shaft that is now covered with waste sunk about 100 feet below the large roomlike stope. (See fig. 28.)

The lower Mississippian limestones have a very gentle dip to the west-southwest near the mine but are cut by a strong north-south fault with steep easterly dip a few hundred feet west of the tunnels. The ore occurs in a 40-foot bed of brownish-gray crystalline limestone carrying some chert, immediately above a series of thin-bedded dense blue limestones. The ore is exposed on the surface and the development shows that it is to be found in large and small bodies in the 40-foot bed for a distance of about 190 feet east and west. The large body from which the greater part of the ore has so far been taken occurs below a slip plane that strikes N. 50° E. and dips 40° SE. between fractures that are practically vertical and that strike a few degrees east and west of north. (See fig. 28.) The ore is not cut off by these faults, though along the western one postmineral movement which has left striæ that pitch 75° S. in the 6-inch gouge has moved the eastern segment down between 6 and 8 feet. The original work was all east of this fault and a room stoped about 70 feet long, 40 feet wide, and 30 feet in maximum height is said to have been all ore. Later developments show that the ore continues west of this fault for at least 40 feet in a 4 to 6 foot bed, the western limit of which had not been reached in September, 1912. The tunnel is in barren limestone under the ore, and it is reported that the shaft was sunk in barren ground. It has not yet been demonstrated that the ore goes north into the hill along either the particular bed or the flat fault zone.

The ore is practically pure white smithsonite that occurs both in massive and in banded form. Along the west fault plane there is some brownish-gray calamine, varying from 6 inches to 1 foot in width, which was deposited in open spaces subsequent to the last movement. The croppings show some hydrozincite, and it is possible that some of this mineral may have been mined with the smithsonite ore that came from the large stope. It is said that during three months' operation 100 cars of ore which did not require any sorting and carried more than 40 per cent of zinc were shipped from this body.

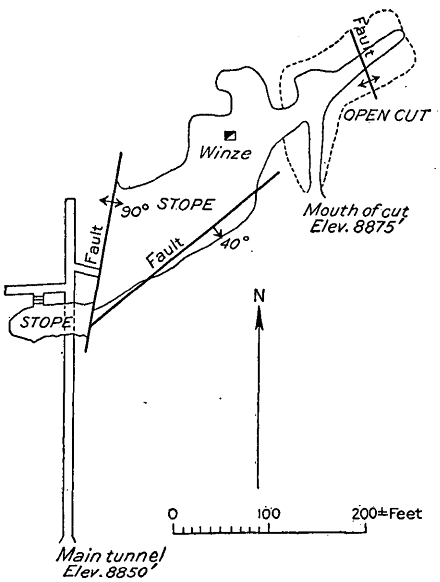


FIGURE 28.—Sketch of the Monte Cristo ore body and developments, Clark County, Nev.

ACCIDENT MINE.

The Accident mine (No. 27, Pl. IV) is in the first canyon south of the Monte Cristo mine at an elevation of 4,200 feet. This claim belongs to Yount & Fayle, of Good Springs, who have leased it to Harry Vail. The mine is developed by an irregular, slightly inclined tunnel running west-northwest into the ore bed for 250 feet, from which there are several small roomlike stopes.

The mouth of the tunnel is about 75 feet west of a strong north-south fault. East of this fault the limestones are rather thin bedded and of a blue color; west of it there are buff-gray crystalline limestones, which at other places usually underlie the thin-bedded formations. West of the fault the limestones dip 5° W.; east of it the dip is a trifle steeper, but in the same direction. The fault zone is marked by about 20 feet of limestone breccia consisting of small fragments in a matrix of crystalline calcite.

The Accident ore is found in a 2 to 4 foot bed of gray, somewhat cherty limestone immediately under a rather heavy bed of cherty blue limestone that has escaped crystallization. It consists of masses of galena coated with anglesite in a reddish-buff sandy matrix that is largely limonite but contains some cerusite. There are usually bands of fairly pure galena on the roof and floor of the ore zone, and in some places there is also a central band. The galena ore is easily sorted and is said to carry about 80 per cent of lead and 9.6 ounces silver and 60 cents in gold to the ton.

About 200 feet from the mouth of the tunnel the ore body has been displaced by a fault which strikes N. 30° W. and dips 75° NE. Northeast of this fault the ore horizon is 12 feet lower than on the southwest side.

BONANZA MINE.

The Bonanza mine (No. 28, Pl. IV) is about 1 mile south of the Monte Cristo, on the hills overlooking the Ivanpah Valley. In 1912 it was under lease to Tursick & Miller.

The country rock is buff-gray crystalline limestone with some dark-gray beds which strike north and south and dip 15° W. They are apparently undisturbed by faulting in the immediate vicinity of the ore bodies.

Two ore bodies were being worked in 1912. The lower was an irregular replacement of lightly iron-stained smithsonite along the bedding of the darker limestone and was developed by a 50-foot tunnel. The upper deposit, 150 feet above the zinc ore, is essentially a deposit of galena along a bed of buff limestone. The galena is altered to some anglesite and considerable cerusite. The deposit is developed by a 30-foot incline and an irregular stope that was 30 feet long and 20 feet in extreme height. The ore varies from 1 foot to 5 feet in thickness. The replacement, while practically parallel to the bedding, is irregular, so that much ore is left on the walls in breaking.

ANCHOR MINE.

The Anchor mine (No. 29, Pl. IV) was the southernmost mine visited on the east side of Spring Mountain. It is located about 7 miles west-southwest of Jean. This property belongs to Yount & Fayle, merchants at Good Springs, and has been worked by them at various times. The larger part of the ore has been taken from open cuts and a short north-south tunnel. A tunnel which runs N. 70° W. into the cliff and at the end of which there is a 40-foot winze with a short drift to the west at the bottom is in great part away from the main fracture, which lies east of the mouth of the tunnel. The country rock is a buff-gray crystalline limestone formation whose beds strike north and south and dip 10°–15° W. This is cut by a north-south vertical fault, along which there is a 2-foot zone of breccia, though the rock for 10 feet on either side of it is more or less broken and creviced. The largest bodies of ore are found in this zone, though one large mass at the mouth of the 70-foot tunnel trends east and west. Some small irregular bodies of ore occur in the tunnel even at a distance of 90 feet from the main fault, but it seems more probable that the largest bodies will be found near the fault.

The ore is of the mixed type which could best be concentrated, though by hand sorting two products have been obtained. The zinc is practically all in the form of carbonate, usually somewhat iron stained. The lead occurs mostly as galena coated with anglesite, and but very little cerusite was seen.

The mine is situated in a very steep side canyon which follows the fault plane, and can be reached only by a narrow sled trail half a mile in length to the loading platform.

Yount & Fayle are reported to have made several small shipments at various times from this property.

OTHER MINES ON THE EAST SIDE OF THE MOUNTAINS.

Several copper prospects are located along the great fault between the Ninety-nine and Contact groups. The Double-up mine was not working in 1912, but is reported to have a good showing of oxidized copper ore. There are several prospects of both lead and zinc ores in the vicinity of the Monte Cristo, and at one place 1 mile north of that mine considerable money has been spent in constructing ore bins, chutes, etc. It is said that there are several good zinc prospects northeast of Diablo Grande Peak, but none of them were visited.

SURVEY PUBLICATIONS ON LEAD AND ZINC.

The following list includes the more important papers 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. The publications marked "Exhausted" are no longer available for distribution but may be seen at the larger libraries of the country.

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CROSS, WHITMAN, HOWE, ERNEST, and RANSOME, F. L., Silverton folio (No. 120), Geol. Atlas U. S., 1905. 5c.

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ELLIS, E. E., Zinc and lead mines near Dodgeville, Wis.: Bull. 260, 1905, pp. 311–315. Exhausted.

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EMMONS, S. F., and IRVING, J. D., The Downtown district of Leadville, Colo.: Bull. 320, 1907, 72 pp.

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IRON AND MANGANESE.

PRELIMINARY REPORT ON THE RED IRON ORES OF EAST TENNESSEE, NORTHEAST ALABAMA, AND NORTHWEST GEORGIA.

By Ernest F. Burchard.

INTRODUCTION.

PURPOSE OF INVESTIGATION.

The attention of the iron makers of the United States has been turning toward the southern iron-ore fields to a considerable extent during the last decade, but more particularly since it has been proved possible to make basic open-hearth steel from southern iron ore. In response to many inquiries for information concerning the ore fields and the utilization of the ores the State geological surveys of Alabama and Georgia have already issued special reports on these subjects, and the United States Geological Survey has issued Bulletin 400, giving a detailed description of the Birmingham district, Alabama, and several short papers in which inter-State areas are considered, as in the present paper. (See footnote, p. 281.) The Tennessee Geological Survey is about to publish a detailed bulletin by the writer on the red iron ores of east Tennessee. This Tennessee material will, it is expected, be combined with details concerning the ore-bearing area in northeast Alabama and northwest Georgia, extending from the Birmingham district to the Tennessee border, and the whole published as a bulletin by the United States Geological Survey. The completion of this proposed bulletin is awaiting the results of field work that is planned to be done in Alabama between the Birmingham district and Attalla and along Tennessee River northeast of Guntersville. When the proposed bulletin is published reports will be available on the red iron ores of the southern Appalachians from southwest Virginia to north-central Alabama, where the Appalachian ridges become buried by the Mesozoic and Cenozoic deposits of the Coastal Plain.

Most of the field work on which this report is based was done in the autumn of 1911, although the writer has drawn freely on notes made by him during visits to certain mines in 1906 and 1908. The greater part of the expense was borne jointly by the United States Geological Survey and the State Geological Survey of Tennessee. The Chattanooga Chamber of Commerce made a contribution which was used to defray part of the expenses of prospecting.

The work of prospecting was in charge of Mr. J. R. Ryan, a mining superintendent and contractor of Chattanooga. Mr. Ryan measured many of the sections described in this paper and in many other ways rendered valuable assistance. It is largely due to the thorough knowledge of the Chattanooga district possessed by Mr. Ryan and to the loyal and generous spirit in which he served the State that the field work on which this report is based was accomplished within the funds allotted for the purpose.

The city of Chattanooga lies within 4 miles of the southern boundary of Tennessee, and as there are more important reserves of red iron ore within 30 to 40 miles to the south of the city than within an equal distance to the north it was the desire of the Chattanooga Chamber of Commerce that part of the funds allotted for prospecting should be used in Alabama and Georgia, in order to demonstrate the value of the ores tributary to the city. The prospecting was accordingly done without reference to State boundaries.

PROSPECTING THE ORE BEDS.

As a rule the author of a report on the bedded iron ores of an area in the southern Appalachians has been obliged to depend entirely upon natural exposures of the ore beds or upon exposures made by mining operations, roads, tunnels, etc. The soft, shaly nature of much of the rock overlying the red ore causes the shale above a fresh ore prospect to "slump" down within a few months and practically to cover up a showing of ore. The result is, therefore, that except where mining is actually in progress there are very few exposures of ore beds, even though many fresh prospects may have been made within a year. The geologist who attempts to prepare a report on a bedded ore field must either accept much hearsay evidence concerning the thickness and character of the ore beds, or else he or a member of his party must see and measure every section on which the report is based. The latter plan was consistently carried out in the field work of the present investigation. In order that no very long gaps should occur between measured sections the ore beds were prospected on the outcrop at points where measurements were of most importance. In many places it was necessary only to clean out old prospect pits, but in others fresh pits were dug. Wherever practicable the bed was cut back to firm ore, in order to ascertain the true thickness of the ore. At many of these prospects samples of ore were taken for analysis by the Survey.

SCOPE OF THIS PAPER.

This paper summarizes the results of the writer's recent investigations of the red iron ore beds in east Tennessee, northeast Alabama, and northwest Georgia, and includes quotations from a paper by C. H. Gordon and R. P. Jarvis on a special area in east Tennessee and from a paper by S. W. McCallie on an area in Georgia. The geology of the region has received so much attention in other publications of the Federal Survey and in State Survey publications that no space will be devoted here to that phase of the subject.[1] Two general maps are presented herewith (Pls. V and VI) to illustrate the relations of the outcropping ore beds to the coal-bearing areas and to transportation routes and other commercial features. One map and one structure section (figs. 29 and 30) have been introduced to show the topographic relations of a body of residual ore near Sweetwater, Tenn. On the general maps areas of outcrop of ore beds generally 2 feet or more in thickness and areas where the beds are generally less than 2 feet thick are differentiated by means of special symbols. As the ores associated with the Tellico sandstone and the Grainger shale have not previously been described, they will be given more attention here than would perhaps be warranted by their importance, compared with the ore of the "Rockwood" formation.

ORE-BEARING FORMATIONS.

Although many of the formations in the southern Appalachians contain small quantities of iron oxide scattered through the beds, only three formations have been found to contain quantities sufficiently concentrated to warrant their classification as red ore bearing formations. Beginning with the lowest these formations are the Tellico sandstone, of Ordovician age; the "Rockwood" formation, of Silurian age; and the upper or Mississippian part of the Grainger shale.

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[1] See Folios 2, 4, 6, 8, 16, 19, 20, 21, 33, 35, and 75, Geol. Atlas U. S., also the following papers:

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In southern Tennessee south of Chattanooga and in northwestern Georgia the lower part of the "Rockwood," which contains in places thin seams of oolitic iron ore, is, according to E. O. Ulrich, of Ordovician age. None of the ore seams that have been noted in these beds are thick enough to be mined except in a small way along the outcrop.

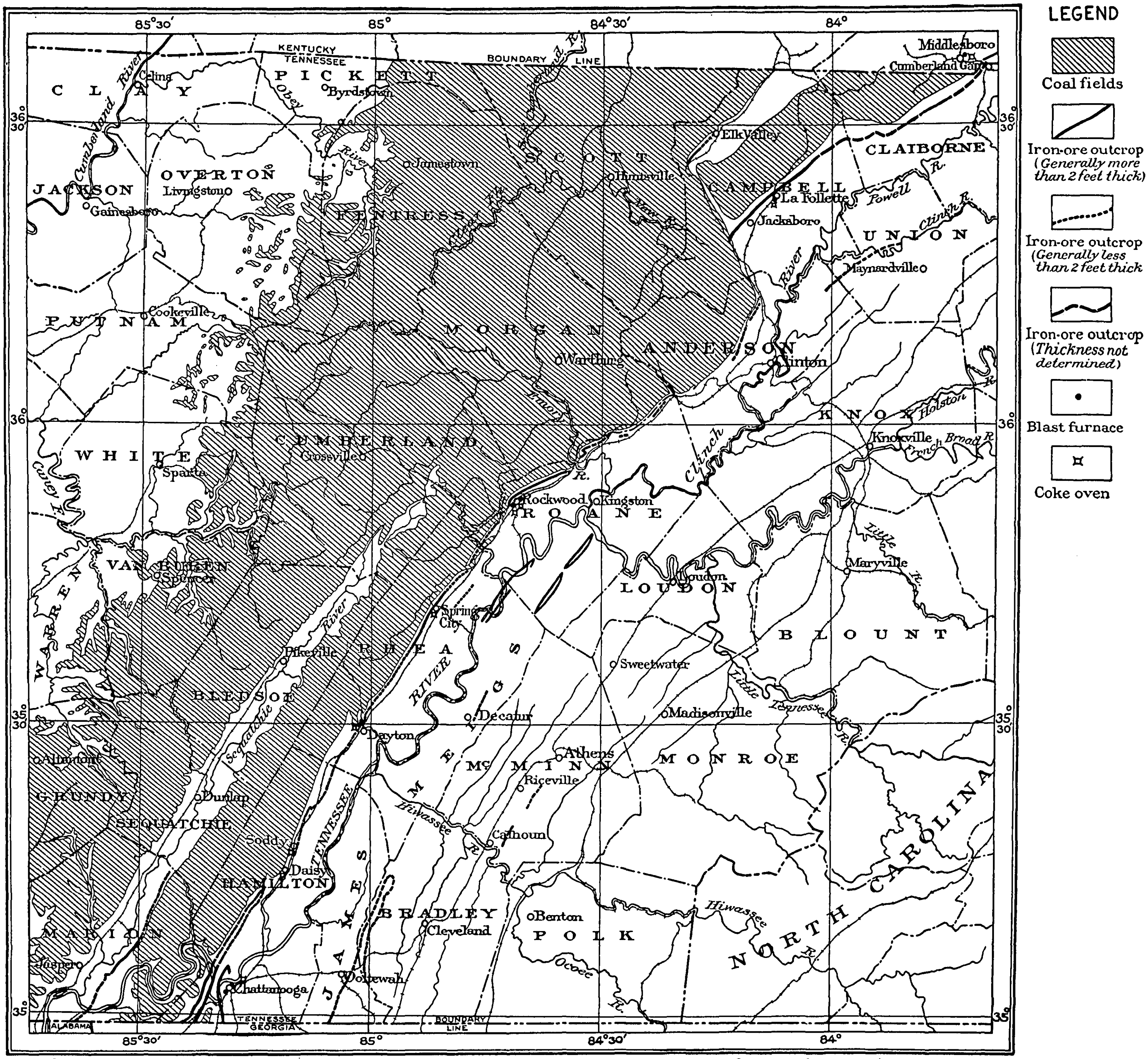
THE RED IRON ORES.

GENERAL FEATURES.

By the term "ore" in this report is meant such ferruginous material as may have a value either at present or in the near future as a source of iron, whether or not it occurs in quantities sufficient to warrant mining. At present no ores carrying less than 25 per cent of metallic iron are intentionally charged alone into blast furnaces, and ores as lean as this can not be used economically unless they carry more than enough lime to flux them and are also used in connection with richer ore. As there are in the southern Appalachians enormous reserves of ore carrying 25 per cent or more of iron, it seems hardly necessary in this report to consider as an ore anything leaner than the 25 per cent grade. It is, however, difficult to draw a rigid line. For instance, other things being equivalent, it would be more desirable to use as a flux a limestone carrying 15 to 20 per cent of ferric oxide (10.5 to 14 per cent of metallic iron) than one containing only 3 to 5 per cent of ferric oxide, on account of its higher iron yield. Nevertheless, such a ferruginous limestone would not commercially be styled an ore, while a bed carrying 25 per cent of metallic iron (35.5 per cent of ferric oxide), although in itself hardly rich enough to be used alone for the manufacture of iron, would be conceded to be an "ore." In view of this commercial distinction material carrying less than 20 per cent of metallic iron will not be considered as an iron ore in this report.

The type of iron ore commonly known as red ore is composed essentially of red hematite, or anhydrous ferric oxide (Fe_2O_3), together with a variety of impurities, such as silica (SiO_2), alumina (Al_2O_3), carbonate of calcium ($CaCO_3$), carbonate of magnesium ($MgCO_3$), sulphur (S), phosphorus (P), and manganese (Mn). Here and there a little hydrous iron oxide (brown ore) is mixed with the hematite, but it has resulted from the hydration of the hematite—that is, the chemical combination of water with the ferric oxide—and does not occur in sufficient quantities to affect the composition of the ore greatly.

The distinguishing characteristic of the red ore is its occurrence in beds or thin lenticular masses of great linear extent, analogous to strata of shale, limestone, and sandstone, and it is interbedded with



Base from U.S. Post Route map of Tennessee

Coal areas from geologic folios of U.S. Geological Survey; iron-ore outcrops mapped by E. F. Burchard

MAP SHOWING RELATION OF RED IRON ORES TO COAL FIELDS, TRANSPORTATION ROUTES, AND INDUSTRIAL CENTERS IN EAST TENNESSEE.

such rocks. One notable deposit is described in this report which is due to the concentration of residual fragments and powder of red iron ore derived from bedded deposits.

IRON ORE IN THE TELLICO SANDSTONE.

CHARACTER.

Interbedded with the shale in the Tellico sandstone there are in a few localities in east Tennessee and northwest Georgia thin seams or lenses of hematite of moderate extent. Such ore as was noted during the present study varies from a ferruginous calcareous sandstone to a rich, compact material composed mainly of iron oxide and having a relatively high specific gravity. Some of the ore is calcareous and contains many fossil remains. The richest beds range in thickness from a few inches to 18 inches, and much greater thicknesses of lean material have been measured. Where the Tellico sandstone has been disintegrated by weathering and the fragments of residual ore have been concentrated in basins on the surface of harder rocks, deposits of economic importance may be formed. Such deposits occur near Sweetwater and east of Knoxville, Tenn.

DISTRIBUTION IN TENNESSEE.

Although attention has been directed to the iron ore in the Tellico sandstone only in a few places in Tennessee, namely, east of Knoxville, between Holston and French Broad rivers, near Sweetwater, Monroe County, and near Riceville, McMinn County, there are probably other areas in which this formation carries ore of similar character.

DEPOSITS NEAR RICEVILLE.

LOCATION.

The ore noted near Riceville is included in the Tellico sandstone belt that extends northeast and southwest nearly parallel to and 1¾ to 2¼ miles east of the Southern Railway north of Hiwassee River.

TOPOGRAPHIC AND GEOLOGIC RELATIONS.

The Tellico sandstone occupies a dissected ridge that rises 300 feet above Oostanaula Creek. This creek cuts through the ridge near Athens and flows along the east side of the ridge to a point nearly opposite Riceville, where it crosses to the west side and follows the base of the ridge nearly to Hiwassee River. The Tellico here consists of shale, sandstone, and thin beds of limestone, the shale predominating. The formation outcrops on the west limb of a syncline, and the dips are generally about 20° S. 75°–80° E.

ORE BEDS.

There are at least two ferruginous beds in the Tellico in this vicinity. The lower of the two observed lies apparently in the lower third of the formation and the upper bed lies, as nearly as could be determined in driving across the formation, in the upper third. The lower ore bed is exposed at a point about 2½ miles southeast of Riceville, where it consists of hard, compact dark-red ore, with a metallic luster. The thickness averages about 9 inches and the range in thickness, measured along a trench 100 feet or more in length, is 6 to 14 inches. The ore is laminated parallel to the bedding and splits easily. It is also jointed perpendicular to the bedding. The material is fossiliferous and overlies a bed of fossiliferous crystalline limestone, gray to chocolate in color. The dip of the bed is 20° S. 75° E.

At this point the ore had been opened many years ago by trenching along the outcrop and stripping to a depth of 10 feet. Three carloads of ore thus obtained are said to have been shipped in 1888 or 1889 to the Citico blast furnace at Chattanooga. It is stated that at that time it cost 75 cents a ton to mine the ore, 75 cents to haul it to the railroad at Riceville, and 66⅔ cents for freight charges to Citico, and that the ore sold for $2.50 a ton, delivered. Judged by the appearance of samples and the analyses, given below, this ore is of excellent quality, but where it was observed it is too thin to be worked except by further stripping, and there is not much ore available for stripping. If the ore should be found to be of workable thickness underground toward the southeast, it might be advantageously worked by means of tunnels driven into the east slope of the ridge at a lower altitude. Considerable prospecting by drilling or tunneling would be necessary in order to determine the thickness, however.

The lower seam of ore was noted also about 4 miles northeast of Calhoun, on the hillside north of Meadow Fork. At this point the ore is only about 6 inches thick, and in places its color is dark, suggesting the presence of manganese oxide. The dip here is 20° S. 80° E.

The upper bed of ferruginous sediments noted in this vicinity displays great variation in character. At a point on the southeast slope of the ridge, about 2¾ miles east-southeast of Riceville (Pl. V), a prospect pit disclosed about 3 feet of ore, but the full thickness could not be determined because the bed was not fully exposed. The position of the mass suggested that it might be a bowlder that had become separated from its original bed. The ore is hard, compact, and dark red, apparently contains much silica, and breaks into prismatic fragments that show slickensides. The dip of the beds here is 20° S. 80° E. The upper ore bed was also noted near Meadow Fork about 4 miles northeast of Calhoun. At this point there is

10 to 12 feet, and possibly more, of ferruginous sandstone. This sandstone is decomposed and rather soft where observed in a road cut. It lies in thin to medium-thick beds, dipping 20° S. 80° E. The color is dark red to brown, but the rock here is apparently too low in iron oxide to be of value as an ore of iron at present. It is reported that several openings have been made on this seam at other places and that where the ore is hard and not decomposed it is of much better quality.

ANALYSES.

The following analyses show the character of the ore near Riceville:

Analyses of soft iron ore from vicinity of Riceville, Tenn.

[Authority, W. M. Bowron.]

Locality.	Fe.	SiO_2.	P.	S.	H_2O.
McMinn-Thomas bank	56.65	9.67	0.52	0.09	7.85
McCamey	60.21	13.82	.72	.09	1.02
Dodson Ridge	60.03	13.34	.13	.12	1.32
Carruths Place	56.58	18.05	.65	....	1.10
Meadow Park and Dodsons	43.32	32.18	....	....	....

DEPOSITS NEAR SWEETWATER.

LOCATION.

The iron ore 1½ to 3½ miles northeast of Sweetwater extends in a northeast-southwest direction and throughout its extent is from one-half to three-fourths of a mile southeast of the Chattanooga & Knoxville division of the Southern Railway. (See fig. 29, p. 286.)

TOPOGRAPHIC AND GEOLOGIC RELATIONS.

The ore lies on the southeast side of the Sweetwater Valley within 1 mile of the creek. It occupies a position not quite halfway to the summit of the divide and is between 75 and 150 feet above the level of Sweetwater Creek. The surface of the deposit is irregular, owing to erosion. In one place, where thickest, the deposit forms a gently rounded hill, and in another it is entirely cut through by a small branch that flows northwestward into Sweetwater Creek.

The deposit overlies the Chickamauga limestone and occupies a depression of irregular depth on the surface of that formation. The prevailing dip of the rocks is about 15° SE. Southeastward from Sweetwater Creek occur the following formations in an ascending scale: Knox dolomite, Chickamauga limestone (including the Holston marble lentil), and Tellico sandstone. The Tellico is partly buried beneath the Knox dolomite along an overthrust fault on the southeast. These relations are shown in the structure section (fig. 30, p. 287).

The upper portion of the Knox dolomite is exposed between Sweetwater Creek and the overlying Chickamauga limestone to the southeast. The residual clay from the Knox contains considerable chert, but where the rock beds are exposed they are generally grayish magnesian limestone. The Chickamauga is a mottled blue and buff dense to partly crystalline fossiliferous limestone. In places films of limonite appear on weathered ledges, but they do not extend far into the rock. The Holston marble in this area is a chocolate-colored to reddish-brown, medium coarsely crystalline stone, containing in some layers considerable ferric oxide. The Chickamauga limestone, including the Holston marble lentil, is 500 to 700 feet thick.

The Tellico sandstone, more appropriately termed shale in this locality, is principally a yellowish sandy shale, with two or more seams of iron ore locally developed.

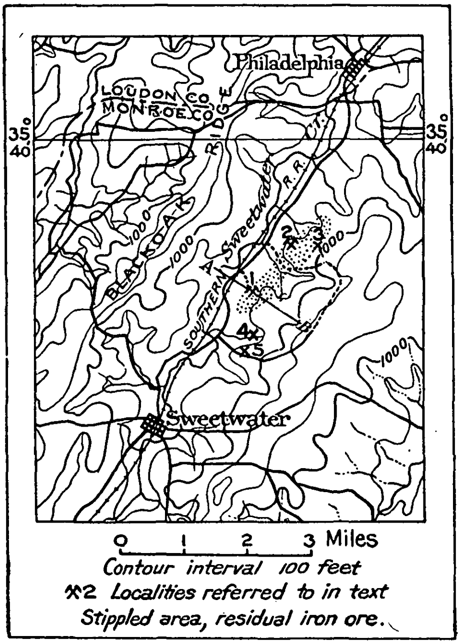


FIGURE 29.—Map showing geographic and commercial relations of residual hematite deposit near Sweetwater, Tenn. Topography from map of Loudon quadrangle, U. S. Geol. Survey. *A-B*, Line of section, figure 30.

CHARACTER OF THE ORE DEPOSIT.

If scattered lumps of iron and manganese oxides had not been plowed up by farmers in tilling the bright-red soil of this locality, the possibility of the existence of ore in commercial quantity might never have been suspected. The abundance of these fragments in the fields and in gullies where they had been washed out of the soil led to the opening of some pits for the production of manganese ore a dozen years ago. After a few hundred tons of manganese ore (psilomelane) in lump form had been shipped work was abandoned, but several years later a number of pits were sunk in the hope of finding more abundant supplies of manganese, and in these pits a peculiar dark-reddish to bluish-black soft claylike substance was found which proved on analysis to be rich in ferric oxide. One of these pits, about 20 feet deep, showed the following succession from the top downward: Residual soil, red sandy clay, smooth fine-grained dark bluish-red clay, manganese oxide gravel, lumps of red iron oxide, black banded clay, and at the bottom fossiliferous ferruginous limestone dipping 8° to 10° SE. The manganese ore carried 43 to 46 per cent of metallic manganese and a little iron. Another pit showed at the top 3 to 5 feet of ferruginous soil with tough hard slickensided angular fragments of iron ore, from half an inch to 12 or 15 inches long, mixed with nodular lumps of manganese ore. Below this a bed of bluish-red granular clay, 4 to 6 feet thick, lies like a blanket, following the contour of the hill. This material gives a bluish-red graphitic smut when rubbed between the fingers. The bed next below is about 6 feet thick. It is darker, but is of a lower specific gravity than the bluish material. In other pits this horizon is occupied by yellowish and black clay mixed. No rock was struck in several pits, but ferruginous limestone was noted at a lower level on the hillside toward the west. One pit which was started in on the limestone disclosed a very irregular rock surface with gravel iron ore lying in depressions in the limestone and covered by clay. Here and there in the ore gravel and more abundantly among the surface ore fragments are found waterworn pebbles of white sand-

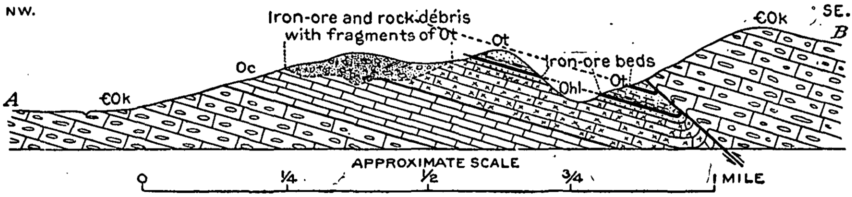


FIGURE 30.—Northwest-southwest structure section near Sweetwater, Tenn., along line *A-B*, figure 29, showing position of residual iron ore deposit and relation of Tellico iron ore beds and ferruginous Holston marble to the ore beds. €Ok, Knox dolomite; Oc, Chickamauga limestone; Ohl, Holston marble lentil of Chickamauga limestone; Ot, Tellico sandstone.

stone and quartzite. When moist all the clay is darker and shows less red color than when dry.

The unique feature of this deposit, so far as this region is concerned, is that the dark bluish-red and steel-colored clay and some of the reddish surface clay really constitute an earthy iron ore. The dark variety is usually manganiferous, but some of the earthy material, though high in iron, contains only a little manganese. This locality was first visited by the writer in 1906. At that time mining was in progress and about 150 carloads of iron ore (more than 5,000 long tons) had been shipped, principally to blast furnaces in Chattanooga. The deposit was again visited in 1911, after considerable more mining had been done. The largest pit from which the material had been mined is near the top of the hill (No. 1, fig. 29) and had a face of about 25 feet and a diameter of about 100 feet. At the bottom of the pit a shaft had been sunk 40 feet, all in soft ore without reaching rock, but a well dug near the power house, beginning at a level about 10 feet below the base of the pit, reached gray limestone within a depth of 40 feet, showing that the thickness of the loose sedimentary material at that place is nearly 75 feet. Near the entrance to the pit, which is reached by a passageway cut from the hillside, the soft ore and ore débris appear to occur in masses having rounded tops. Layers of manganese gravel follow the contour of the rounded masses. Some of the ore is sandy and shows limonite specks. Streaks of greasy pink hematite, with a graphitic feel, are found; such material is called "iron fat" by miners.

The fragments of hard ore embedded in the soft ore appear to have been broken from a bed in the Tellico sandstone which formerly extended over the area but which has been cut back eastward by erosion and disintegration. Many fragments show slickensides parallel to the bedding and on joint planes. Pieces of ore 8 to 10 inches thick were noted, and masses 3 feet thick are reported to have been found. The fragments of hard ore strongly resemble the red ore occurring near Riceville, which is considered by E. O. Ulrich to be in the Tellico sandstone. These fragments have not yielded many fossils, although one brachiopod and numerous crinoid stems were noted. The ore is also oolitic or granular in places. The hard fragments appear to have been derived from two or more beds, one rich in iron and the other lean and sandy—this also being a point of resemblance to the ore near Riceville. In the ferruginous earth forming the walls of a pit formerly worked for manganese ore (No. 2, fig. 29) about three-fourths of a mile northeast of the pit first described, masses of yellow sandy shale, waterworn pebbles of white quartz sandstone, and angular pieces of buff fine-grained sandstone were found. Similar sandy shale occurs in place on the hillside about a quarter of a mile east of the old manganese pit, in the area mapped as Tellico sandstone in the Loudon geologic folio.[1] It overlies crystalline limestone belonging to the Holston marble lentil of the Chickamauga limestone. Two pits in which an ore seam had been cut were noted in this shale. One pit (No. 3, fig. 29) is in the lower part of the formation, 15 to 25 feet above the highest observed outcrop of Holston marble, and about half a mile northeast of the "soft ore" mine. The other pit (No. 4, fig. 29) is about three-fourths of a mile south of the ore mine. A bed about 4 inches thick, dipping about 15° SE., appears in the pit at point No. 3. This bedded ore is rich in iron, fossiliferous, and granular but has been leached so as to be spongy in places. In the pit at point No. 4 the ore is evidently much thicker, although the pit was covered and the thickness could not be measured. Several tons of ore lie on the dump. The ore from this pit is very rich in iron. It is mostly hard, compact, and brittle, breaking into blocks with bright slickensided faces. It is reported that this bed ranged from 18 inches to 3 feet in thickness but pinched out to almost nothing within a few yards, and

[1] Loudon folio (No. 25), Geol. Atlas U. S., U. S. Geol. Survey, 1896.

prospecting was therefore discontinued. This pit is south of the limit given by Keith in the Loudon folio for the Tellico sandstone in this vicinity, but the shale shows plainly in the wagon road half a mile farther south, where the ore also outcrops with a thickness of about 30 inches (No. 5, fig. 29). The beds dip about 15° SE., and if projected northwestward would lie above the present surface of the soft ore.

ORIGIN OF THE ORE DEPOSIT.

The fragments of hard ore appear to have been derived from the ore beds in the Tellico sandstone, but another important source of ferruginous material in this locality is the Holston marble. Some beds of this rock contain 15 to 20 per cent of ferric oxide. When the calcite is leached out a large iron oxide residue is left. This is well shown on the weathered edges of some beds of the marble and by fragments from which the lime has been dissolved. In the Chickamauga limestone below the Holston marble lentil there are streaks of limonite ranging in thickness from a knife edge to three-fourths of an inch running irregularly through some beds. Both the topographic and the geologic relations of these three iron-bearing formations suggest that the deposit is residual from (*a*) the hematite beds in the Tellico sandstone that once extended over the area, (*b*) the ferric oxide in the Holston marble lentil of the Chickamauga limestone, and (*c*) the limonite streaks in the other limestones of the Chickamauga. Surface water has assisted in the concentration, as is indicated by the rounded, waterworn pebbles of sandstone that have been carried into the deposit and by the distribution of the nodules of manganese oxide in strata and pockets near the top of the mass of soft ore.

The most notable characteristic of the deposit is the large proportion of hematite present. Throughout the Appalachian Valley occur scattered deposits of limonite, most of which are residual from the limestone beds that have been removed by solution, but nowhere else in the South has the writer seen a deposit of residual iron ore that is composed so largely of hematite. In this respect it resembles, on a small scale, some of the deposits of residual ore in the iron ranges in Minnesota. It is not improbable that similar deposits may be found at other places in east Tennessee where the topographic and geologic conditions resemble those at Sweetwater.

MINING.

Prior to 1907 mining was at first accomplished here by cutting down the bank with picks, carting away the stripping, and moving the raw ore in wagons to the siding on the Southern Railway, about three-fourths of a mile distant, where it was dumped into cars and shipped to Chattanooga. Attempts were later made to briquet the ore, and a stiff-mud brick-molding machine was erected. The soft ore was trammed from the pit on small cars, mixed with a little water, made up into about 100,000 bricks, built up in kilns, and burned just hard enough to enable them to stand handling and transportation, most of the moisture being driven off by the process. The ore so treated is reported to have cost $1.26 a ton to mine and briquet and to have been successfully used in the briquetted form by certain blast furnaces. It was not possible to maintain a sufficiently large output from this plant and its use was discontinued. but the results of the briquetting demonstrated that the quality and physical condition of the ore could be much improved through some method of concentration and conversion to a more solid state. Consequently preparations were made first to develop a large output of the ore, and next to install an ore-sintering plant.

In October, 1912, a 20-ton steam shovel was started stripping cover and digging ore. The ore was loaded into mine-dump cars that carried the ore about 900 feet toward the railroad and dumped it into wagons, in which it was carried the remaining five-eighths of a mile to the railroad. Nearly 8,000 long tons of ore is reported to have been shipped to blast furnaces in 1912. Average analyses are said to have shown a little more than 40 per cent of metallic iron and between 2 and 3 per cent of manganese. It is stated that another steam shovel is soon to be installed and that the construction of 1,200 feet of new siding from the Southern Railway to the site of the sintering plant is under way (January, 1913). It is reported that the sintering plant is to be built by the American Ore Reclamation Co. and will comprise four Dwight-Lloyd sintering machines. This plant is planned to produce 400 tons of sintered ore daily, and it is considered that this sinter, which is cellular in structure, should require much less coke than is required to reduce natural iron ores.

It is said that prior to installing the steam shovel 200 acres of this ore land was surveyed and platted, 40 test holes 15 to 80 feet deep were sunk 100 to 200 feet apart, cross sections were drawn, and analyses were made of samples of the ore taken every 5 feet from the test holes, but none of the results of this work could be obtained for inspection by the Survey.

According to reports of recent operations the costs for mining by steam shovel, hauling, and loading the ore on railroad cars were reduced to a very much lower average than before the steam shovel was installed, and it is expected that these costs will be still further lowered when a tramway entirely supplants hauling by team.

A good market is assured for several times the proposed daily output of this mine and sintering plant, so that if the ore exists in sufficient quantity and the beneficiation proves successful the future exploitation of this deposit should be very promising.

ANALYSES.

The following analyses show the character of the ore near Sweetwater:

Analyses of iron ore from vicinity of Sweetwater, Tenn.

	Authority.[a]	Fe.	SiO_2.	Al_2O_3.	CaO.	Mn.	P	S	H_2O.
Unconsolidated ore	O	46.90	b20.16		....	2.12	....	....	....
		....	....	7.41	....	....	....	....	....
		32.30	44.92	5.61	....	....	....	....	....
		45.18	16.27	....	....	....	....	....	....
		43.91	23.30	....	....	....	....	....	....
Do	E	52.32	8.52	7.73	....	2.50	1.71	....	....
Do	Ch	47.84	b16.22	11.41	....	2.78	.51	....	....
Do	Ch	50.75	b17.20	10.16	....	....	....	....	....
Do	Ch	59.20	5.30	....		....	.22	....	....
Do	Ch	33.86	b43.80	6.10	....	2.43	.435	....	....
Do	L	29.90	b37.52		....	....	....	....	....
Do	L	41.30	b22.78		....	....	....	....	....
Do	L	46.90		7.41	....	2.12	....	....	....
Heiskell tract	L	40.90	b23.98		....	....	.22	....	....
Do	L	35.90	b30.36		....	....	....	....	....
Do	L	53.20	b7.32		....	....	.46	....	....
Prospect sample	L	46.50	b22.56		....	1.18	....	....	....
Do	L	11.10	b68: 56		....	....	....	....	....
Do	L	39.90	b28.44		....	....	....	....	....
Do	L	15.50	b61.94		....	....	....	....	....
Do	U. S.	46.80	15.22	10.02	....	1.75	.12	.05	3.57
"Iron fat" ore	U. S.	47.85	....	....	....	....	....	....	2.82
Ferruginous limestone	Ch	8.71	b4.10		76.90	....	....	....	....
Do	C	12.11	b6.68		....	....	....	....	....

[a] Authorities: C, Citico Blast Furnace Co.; Ch, Chattanooga Iron & Coal Co.; E, Embree Iron Co.; L, La Follette Iron & Coal Co.; O, owners; U. S., U. S. Geological Survey.
[b] Insoluble.

TUCKAHOE DISTRICT.

SOURCE OF DATA.

In view of the interest that is at present being taken in the deposits of iron ore which lie between Holston and French Broad rivers in Knox and Jefferson counties east of Knoxville, Tenn., and which are somewhat similar in origin and geologic relations to the deposit near Sweetwater, described above, it has been decided to present here certain essential data recently published by C. H. Gordon and R. P. Jarvis, of the University of Tennessee, on the iron-ore deposits of the Tuckahoe district. The complete paper was published in the issue of "Resources of Tennessee" for December, 1912, pages 457–478. According to that description, the ore consists of both limonite and hematite, like the ore near Sweetwater, although in the Sweetwater locality hematite predominates. In the Tuckahoe district the limonite has probably been formed, for the most part, through the hydration of hematite, and a similar process has produced much limonite in the soft "Rockwood" ore near Chamberlain. As brown ore of this type is derived directly from bedded deposits of the normal red-ore type, the brown ore is much more closely allied to the bedded red ore than it is to the typical Appalachian Valley brown ores, and it should logically be grouped with the bedded red ores.

The following quotations on this subject are taken from the report by Gordon and Jarvis mentioned above.

THE ORES.

The iron ores of the Tuckahoe district are comprised within a belt approximately 14 miles long and 4 miles wide lying between the Holston and French Broad rivers. The southern extremity of the belt lies approximately 4 miles northeast of the junction of the two rivers and extends in a general northeast direction to McCampbells Knob, situated 7 miles southeast of Straw Plains. The southwest extremity of the belt is about 9 miles northeast of Knoxville. The iron-bearing zone as thus defined is included within the three counties of Knox, Sevier, and Jefferson.

The district is readily accessible by good pike roads from the station of Straw Plains, 16 miles northeast of Knoxville on the Bristol & Knoxville division of the Southern Railway. The southwest extremity can be reached from Knoxville over the Dandridge pike, and with the completion of the branch line of the Southern Railway to the marble quarries between the forks of the Holston and French Broad rivers the deposits in part are brought within a distance of 4 to 5 miles of rail transportation. Owing to the close proximity of the rivers to the entire belt, water transportation is within easy reach.

The formation carrying the iron-bearing beds in this district is known as the Tellico sandstone, a gray and bluish-gray calcareous and ferruginous sandstone ranging from 100 to 300 feet thick, of Ordovician age. The formation derives its name from Tellico Plains, in Monroe County, where it is extensively developed. The outcrop of this formation is usually defined by a well-marked chain of knobs. The iron-bearing member within this formation consists of a ferruginous limestone, but often siliceous in part, which has been thrown into multiple folds, giving rise to a series of parallel veins of beds. All members of the Tellico formation weather rapidly, and owing to this fact and the relatively high iron content in certain beds these have formed, under favorable conditions, considerable accumulations of a very good grade of iron ore.

The analogy between the iron ores in the Tellico and those found in the "Rockford" formation (the "Rockford" iron-ore horizon in Tennessee) is remarkable. This similarity holds not only in the association of the iron beds with the inclosing rocks, shales, and limestones in both cases, but also with reference to the chemical composition of the ores and their physical condition. But the analogy apparently no longer holds when we trace the iron-ore beds of the Tellico beneath the surface. In the case of the Tellico formation it has been found that the concentration of the iron due to the action of surface agencies in leaching the more soluble lime carbonate of the iron-bearing limestone and converting the primary iron carbonate into iron oxide, has not progressed to any great depth. Practically all the openings and prospects made on these veins have either been near the crests of the ridges or knobs or on the steep slopes of narrow hollows and ravines, and usually upon the side of the hill having a southern exposure.

* * * There are three roughly parallel belts of Tellico sandstone, of which the central belt is the longest and the most extensively exploited. This repetition of belts is due, of course, to sharp folding and faulting, and, as explained above, the occurrence of three or more parallel beds or veins is doubtless the result of multiple folds. The multiple-fold structure is very prettily shown at

Moores Knob. Generally the iron veins have a steep dip to the southeast, with the strike conformable with the outcrop of the Tellico formation.

Four localities were examined, viz:

1. Johnsons Knob. Prospects on the farm belonging to G. W. S. Johnson.
2. Maurer's place, or farm now owned by Samuel Vance.
3. Moores Knob, situated close to a farm owned by Jesse Campbell, and on a farm owned by J. R. Moore.
4. McCampbells Knob. Prospects situated on a farm belonging to the McCampbell heirs, and also on other contiguous farms owned by Joshua Cates, Charles Snyder, et al.

From the principal prospects at each of these localities samples were taken, and, where accessible, measurements of the ore bodies were made.

The ore bodies consist of beds of extremely variable thickness, the range being from 1½ to 25 feet or more, as shown in the subjoined table, which is adapted from the paper by Gordon and Jarvis. Some of the beds where unweathered are hardly more than ferruginous limestone, but where weathering has taken place and the lime is leached out the residual material is fairly rich in iron. The beds generally dip at high angles and are exposed high above drainage level, thus affording conditions favorable for deep weathering.

Analyses and other data regarding iron ore in the Tuckahoe district, Tennessee.[a]

No.	Locality.	Prospect or vein No.	Character.	Width sampled.	Fe.	SiO_2.	CaO.	P.	S.
				Ft. in.					
1	Johnsons Knob	1		1 6	48.1	20.16	1.00	0.426	0.06
2	do	2	Unweathered	10	28.0	35.12	.40		
3	do	3		4	43.3	20.68	.60	.295	.76
4	Johnsons Knob, cellar of Johnson's house.			13	50.0	13.32	.40	.498	.27
5	Johnsons Knob	4		12	33.0	36.3	.65		
6	Johnson's dump vein	2			36.7	24.92	.50	.453	.68
7	Vance farm, select ore		Weathered	5	51.3	9.78	2.00	1.001	.42
8	Vance farm, average ore		Mixed ore	7 6	41.2	21.4	1.50	.831	.12
9	Moores Knob	1	Weathered	13	43.6	16.88	.70	.73	.65
10	do	2	Unweathered	4 6	22.0	5.20	27.20		
11	do	3	Weathered	7	34.2	15.2	9.60		
12	do	5	Unweathered	6	19.8	8.88	26.60		
13	Moores Knob, northeast	1		20	23.1	34.10	11.30		
14	do	2		25	29.2	40.00	1.20		
15	do	3	Partly weathered.	9	32.4	36.6	1.80		
16	do	4	Weathered	18	41.7	19.00	4.0	1.023	.45
17	McCampbells Knob	1	do	10	30.5	34.80	1.15		
18	McCampbells Knob (southwest prospect).		do	10	41.4	19.6	2.25	.836	.49
19	McCampbells Knob (dump, Joshua Cates).		Unweathered		11.4	45.00	14.80		
20	McCampbells Knob (dump)		Weathered		40.6	17.20	6.00	.958	.55
21	McCampbells Knob	2	do	6 6	41.0	23.12	.60	.648	.28
22	McCampbells Knob tunnel	2		5	32.0	29.2	1.40		
23	do	2	Mixed ore	5	34.2	13.20	10.80		
24	McCampbells Knob	3		5	42.6	22.0	.40	.669	.55
25	do	4	Weathered	23	42.5	19.0	1.20	1.082	.60
26	do	5	do	6	44.7	13.92	1.75	.616	.52
27	McCampbells Knob (Snyder farm).		do	7 6	49.2	14.28	.90	.959	.46
28	do		do	15	46.0	14.6	2.40	.479	.52
29	do		Unweathered	15	26.6	6.70	22.5		
30	Sample taken from Tellico formation near Charleston, Tenn.				14.0	22.6	26.70		

[a] Analyses 1 to 30, inclusive, were made on moisture-free samples; R. P. Jarvis, analyst.

Analyses and other data regarding iron ore in the Tuckahoe district, Tennessee [a]—Continued.

No.	Locality.	Iron.	Insoluble.	Mn.	P.	Moisture.
31	Johnson's prospect	35.00	31.20	0.44	0.44	3.10
32	Johnson's cellar	53.20	9.50	.97	.25	3.40
33	Vance's prospect	50.40	2.25	Tr.	1.10	1.39

[a] Analyses 31 to 33 by Childress & Hunter.

ORIGIN OF THE ORES.

The evidence that the richness of the iron ores of the Tuckahoe district is due to the leaching out by surface agencies of the more soluble lime carbonate of the iron-bearing limestones of the Tellico formation and the concentration of the iron in the surficial portions is ample and conclusive. As already noted, the exposures are in practically all cases at the tops of knobs and ridges or in narrow hollows and ravines, where erosion has not been sufficient to remove all the products of decomposition. The extent of the deposits is therefore proportional to the depth to which the work of the weather has progressed and the amount of erosion. According to locality, the leaching and the consequent concentration of the iron constituents extends to depths of from 1 or 2 to 40 or 50 feet. In the tunnel on McCampbell property the limestone was encountered 25 feet from the entrance. On making an offset to the right soft ore was found, which extended to the end of the tunnel, a distance of about 50 feet. The more extensive alteration in this portion of the tunnel doubtless finds its explanation in the presence of fractures, permitting the access of water and the consequent leaching of the ferruginous rock. An excellent illustration of this effect of weathering agencies is seen in an outcrop in the north face of the ridge 200 yards southwest of the house on Mr. Snyder's land, in the McCampbell area. Here erosion has removed the products of weathering about as fast as formed. An opening shows the abrupt transition from soft ore to the hard unaltered limestone below. Leaching has progressed irregularily into the rock, following along fractures and crevices, which permitted the easy access of surface waters.

Many other instances may be cited where the indications of the concentration of the iron ores through the leaching of the iron limestone are equally clear and convincing. The prospect shaft put down on Joshua Cates's land west of the McCampbell Knob met with the dark bluish-gray calcareous sandstone (see analysis No. 19) at a depth of about 30 feet, as indicated by the excavated material. The highly ferruginous character of the calcareous beds of the Tellico is shown also by the analyses given (p. 293). It will be readily seen, therefore, that with the removal of the lime by leaching the iron constituents will be concentrated and the deposition thus formed will be confined to the surficial or weathered portions of the formation.

MINING CONDITIONS.

Considerable excitement in the Tuckahoe district was aroused about two years ago, resulting in most of the above prospecting work being done. Estimates of tonnage based upon the results of this prospecting work have been made, but in view of the foregoing facts and an examination of the prospects the writer is of the opinion that even in small and restricted areas, not to mention the entire district, no estimates worthy of the name are possible.

In general, with reference to the character of the ores, analyses have shown that good commercial grades occur in parts of the weathered zone. All the ores are relatively high in phosphorus and therefore non-Bessemer. After passing through the variable but relatively thin weathered zone of enriched ore the veins show a rapid decrease in iron content with increase of depth. This diminution of iron with depth may be expected to continue until the unaltered ferruginous limestone is reached, after which the iron values will ordinarily vary from 10 to 16 per cent. Under present conditions this material can not be considered an iron ore, though in many places in east Tennessee there are literally mountains of it. Possible other uses may be found for it.

Having thus presented the facts in the case so far as present developments have shown, the question as to whether, under present conditions, these deposits can supply a regular and large tonnage answers itself. If it is possible to mine a deposit that occurs in widths and depths varying between 7 to 20 feet and 1 to 12 feet, respectively, where the values are spotted and irregular, where all the work of removing the materials would have to be done by hand, where the iron ore would have to be delivered by cart, wagon, or tramway to some point to be loaded on railway cars, where the topography is that of knobs and ridges, therefore not easily accessible, all at a cost of 75 cents to $1 per ton, then mining may pay. Up to the present time no one has essayed the task. Therefore, until someone has demonstrated that these deposits can be worked at a profit, we must put them into the class of possible future reserves rather than consider them as an immediate source of supply.

DISTRIBUTION IN GEORGIA.

In his chapter on the local distribution of fossil ores in Georgia McCallie[1] writes as follows concerning certain ore deposits of Ordovician age which perhaps should be correlated with the Tellico ore of east Tennessee:

> Besides the above exposures, there are also limited outcroppings of red ores farther east, which are often confounded with the fossil ores. One of the best exposures of these ores is to be seen on the Hoskins farm near the Georgia-Tennessee line, in Whitfield County, about 1 mile east of Red Clay (Dalton quadrangle). The ores here occur along a series of red hills which extend as far south as Varnell's station. Another exposure of these ores may be seen in the northern part of Murray County, along the margin of the metamorphic slates. This series of iron-bearing rocks, which always weathers into a deep-red soil and occasionally carries a limited amount of workable hematite ore, has been described by Hayes under the name of the Tellico sandstone. The formation seems to be of a more recent origin than the fossil ores; nevertheless the similarity of the two ores is often quite marked. Still other iron ores somewhat resembling the fossil ores but probably belonging to the Tellico sandstone occur in Polk County, a short distance north of Rockmart. These ores, which have been rather extensively worked at two or three points along the Seaboard Air Line Railroad, are the weathered outcroppings of a highly ferruginous thin-bedded limestone. Microscopic sections of the unweathered rock show that the ore is present in the form of magnetite. In some parts of the beds where the ores have apparently undergone only partial metamorphism an oolitic structure still remains, thus showing one of the most common characteristic structures of the fossil ores.

[1] McCallie, S. W., op. cit., p. 39.

To this interesting statement it might be added that the writer visited the deposit 2 miles north of Rockmart, in the Rome quadrangle, finding conditions as described by McCallie and also a slight error in the economic-geology map of the Rome folio. The former iron-ore workings were situated about half a mile east of the railroad station designated " Red Ore " on the map, and not at the point about three-fourths of a mile northeast of the station, where a symbol indicates an iron mine. There was, however, at this point formerly a slate quarry. The available iron ore appears to have been practically all mined out, and there is no longer any railroad station designated "Red Ore." On the map referred to the iron ore is mapped as occurring in the area of Rockmart slate.

IRON ORE IN THE "ROCKWOOD" FORMATION.

GENERAL DISTRIBUTION.

The " Rockwood " iron ore in Tennessee, Alabama, and Georgia is nearly but not quite coextensive with the " Rockwood " formation in these States. The exceptions are a few areas where the formation carries little more than a few streaks of ferruginous sandstone or ferruginous limestone. The ore-bearing formation underlies the great plateau areas such as the Cumberland Plateau, Walden Ridge, Sand Mountain, Lookout Mountain, and Pigeon Mountain, which are all broad synclinal areas, and it outcrops in the valleys bordering these plateaus. There are also certain areas of less extent within the valley of east Tennessee and in northwest Georgia, where the iron ore underlies narrow synclinal basins whose continuity has been broken by erosion. The relation of these several areas is shown on the maps (Pls. V and VI).

EAST TENNESSEE.

The " Rockwood " ore in east Tennessee outcrops along the foot of the Cumberland escarpment from the southern border of the State near Chattanooga to the northern border of the State at Cumberland Gap and in several separate areas in the Tennessee Valley. The Cumberland outcrop is not continuous because a number of thrust faults have buried the formation below older rocks. There are, however, strips of outcrop that extend continuously distances of 15 to 20 miles. The normal dip of the rocks along the escarpment is toward the northwest, but in many places the ore beds dip to the southeast, or away from the mountain. This reversed dip is due to the overturning of the strata during the folding of the earth's crust, and it extends from a few feet to hundreds of feet below the surface.

The iron-ore beds extend under the Cumberland Plateau for unknown distances. In the northeastern part of the State the bed is probably continuous between Powell Valley and Elk Valley, the outcrop in Elk Valley being due to faulting and erosion. Near Caryville the southwestward extension of the ore is cut off by a cross fault, which extends northwestward as far as Elk Valley and here again cuts off the ore that is exposed in that valley, thus forming a block of strata bounded on the southeast by Powell Valley, on the southwest by Coal Creek, on the northwest by Elk Creek, and on the northeast by a fault which passes through Cumberland Gap. Along the escarpment between Coal Creek and Harriman the ore is cut out locally by several thrust faults, so that only three small areas of outcrop remain. From Emory Gap southwestward to a point near Glen Alice the ore outcrop is more or less continuous and in the part of this area extending from Cardiff to Rockwood occurs one of the thickest and most valuable portions of the ore bed that has been opened in the State. Between Glen Alice and Spring City there is one considerable break due to faulting, but from Spring City southwestward to Retro the ore outcrop is practically continuous. Between Retro and Rathburn there is a break followed by a strip of ore outcrop about 2½ miles in length, beyond which no ore is found until the valley of Falling Waters Creek is reached. From this creek southwestward to the State line the ore outcrop is practically continuous and is duplicated on both sides of a narrow anticlinal arch. This arched structure is also seen from Hill City southward to the State line in a second outcrop which lies 1 to 2 miles east of the main outcrop at the foot of the Cumberland escarpment and passes through the city of Chattanooga.

In the Tennessee Valley the several areas of "Rockwood" ore are formed by beds that have been folded in among older strata. The largest of these areas are situated near Chamberlain, a few miles south of Tennessee River, in Roane County, and along Tennessee River near Euchee, in Meigs County. These outcrops are mostly in the form of synclinal basins of the "Rockwood" formation modified by more or less folding and faulting. Just northeast of Decatur lies a small area which is bounded on the east by a fault, and farther south Whiteoak Mountain forms the west limb of a syncline in which ore occurs, extending from the State line northward several miles from Ooltewah. Soft ore has been stripped from the outcrop along nearly the whole extent of outcrop in the State, the only exceptions being in localities so remote from railroads or navigable streams as to make mining unprofitable. The ore has been mined underground at La Follette, to a very small extent near Elk Valley, extensively between Emory Gap and Rockwood, and in a few small drifts or tunnels near Glen Alice. Considerable underground work has been done in the vicinity of Chamberlain and Euchee, and a little near Ooltewah. The possibility of underground mining has of course depended on the thickness of the ore bed and the quality of the hard ore below the limit of weathering, as well as on transportation facilities. (See Pls. V and VI.)

An attempt has been made to distinguish on the maps (Pls. V and VI) between ore that is available or probably available and ore that is not available under present conditions. In the latter class are included ore seams that are so thin as to give no promise of future value and others that probably will not become workable until some time in the remote future when the reserves of more readily available iron ore in the country have become more nearly exhausted and the price has reached a point which will permit exploitation of such ores. Topographic maps have been prepared by the United States Geological Survey covering this whole region, and all of it except two small areas in the southern portions of the Williamsburg and Cumberland Gap quadrangles has been covered by geologic folio maps. The geologic folios that cover the remainder of the region are as follows, named in order from north to south: Briceville (No. 33), Maynardville (No. 75), Knoxville (No. 16*), Loudon (No. 25), Kingston (No. 4*), Pikeville (No. 21*), Sewanee (No. 8*), Chattanooga (No. 6*), and Cleveland (No. 20). A strip about 1 mile wide at the north edge of the Stevenson (No. 19*) and Ringgold (No. 2*) quadrangles completes the area within the State of Tennessee to the south of the Sewanee and Chattanooga quadrangles. The folios marked with an asterisk (*) are out of print; the others may be obtained from the Director of the United States Geological Survey.[1] In the geologic folios the general geology and structure have been described by means of maps, structure sections, and discussions in the text. In certain of the folios the distribution of the "Rockwood" formation has been shown to be more extensive than it is now believed to be. At the time the folio surveys were made data were obtained with regard to the ore beds, and it was assumed that the ore did not extend much below water level. The continuity of the beds to depths far below water level has been proved by recent mining work. In the northern part of Sequatchie Valley, in the Pikeville and Chattanooga quadrangles, recent work has shown, according to E. O. Ulrich, that much of the formation formerly mapped as "Rockwood" is not of Clinton age but is older, and that it does not carry ore beds of importance. In the lower part of Sequatchie Valley, near Inman, the

[1] Owing to damage done by a recent fire in the basement of the Geological Survey building the price of these folios has been reduced to 5 cents a copy.

beds of ore have been mined extensively both on the outcrop and underground a number of years ago, but northward from the vicinity of Inman the ore thins abruptly and in a short distance becomes so lean that it is unfit for consideration.

If placed end to end the outcrops of "Rockwood" ore along the base of the Cumberland escarpment, but a single seam being considered, would aggregate 160 linear miles. If the valley outcrops are similarly considered it brings the total linear outcrop of "Rockwood" ore beds in the State up to 245 miles. Out of this total probably 60 miles of outcrop may be considered as workable for hard ore, so far as quality and thickness are concerned, to whatever distances below the outcrop may be permitted by mining conditions. These distances were determined by scaling off the outcrops as shown in the geologic folios. By measurement on the ground the distance might be appreciably greater, because the scale of the maps is too small to show many sinuosities of the outcrop.

For convenience of description the whole of the east Tennessee red-ore area may be divided into three parts—southeast Tennessee, central east Tennessee, and northeast Tennessee. The first division includes the Tennessee Valley from the south boundary of the State to Evensville and also the Sequatchie Valley and the Whiteoak Mountain area. Central east Tennessee comprises the area from Sheffield northeastward to and beyond Coal Creek, and northeast Tennessee the area from Careyville northeastward to Cumberland Gap, including the Elk Valley.

SOUTHEAST TENNESSEE.

The leading facts with regard to the "Rockwood" iron-ore beds outcropping in southeast Tennessee may be briefly summarized here. Perhaps the most important question with regard to a bed of such ore at a given place relates to its thickness. Next, provided the bed is of a workable thickness, is the question of quality, and third is the question of extent of the beds. With reference to the third question it may be said that "Rockwood" ore outcrops all the way along the foot of the Cumberland escarpment, with the exception of about 6 miles in the vicinity of Daisy, almost continuously from the Georgia line to a point northeast of Evensville, a distance of about 45 miles. In addition to this length of outcrop 25 miles of ore measures are brought to the surface by anticlinal and synclinal folds near Chattanooga. In places two to four thin seams of ore occur. The thickness of the ore in some areas is less than 2 feet, as indicated on the map (Pl. VI), but at certain places there is more than 2 feet of ore in the section, as is also shown on the map. In the cut of the

Nashville, Chattanooga & St. Louis Railway 2 miles west of Wauhatchie there is a total of 3 feet 7½ inches of ore in a section of ore and shale aggregating 5 feet 2 inches in thickness. Most of this ore is little more than ferruginous limestone, but to the southwest, in Georgia, the ore bed is richer. A quarter of a mile east of Williams Island the bed showed 2 feet 4 inches of hard calcareous ore. Near Falling Waters a section of 27 feet 6 inches contains 5 feet 3 inches of lean ore, no single bed of which is thicker than 1 foot 1 inch. The outcrops at Hill City showed 2½ feet to more than 3 feet of ore, with one shale parting 2 to 7 inches thick near the middle. The hard ore is lean and calcareous, but there is still some soft and semihard ore here. The "Rockwood" formation at Hill City has a very irregular structure. The beds are considerably faulted and so closely folded as to make deep or extensive mining very difficult. Near Daisy a section showed 2 feet 7 inches of ore within 8 feet 2 inches of shale and ore.

In the Sequatchie Valley, near Inman, there is a strip of indefinite length, probably not exceeding 5 miles, in which a limy ore bed outcrops with a thickness of 2½ to 3½ feet. About 2 miles east of Ooltewah ore-bearing strata of the "Rockwood" formation outcrop on both sides of a narrow syncline whose edges are exposed in Whiteoak Mountain and in a smaller ridge about 2 miles east of it. The ore seams are thin here, ranging from 3 inches to 1 foot 6 inches in thickness, including a few shale streaks. On the east slope of Whiteoak Mountain the ore bed dips generally 22° to 25° SE., but there are many minor crumplings in the strata that vary the dip considerably and make mining uncertain and difficult. In the ridge on the east limb of the syncline red ore occurs north of the Southern Railway, apparently in two beds, but geologic examination has shown that a single bed of ore has been repeated by a close, overturned fold. Locally the same bed is displaced and repeated by an overthrust fault, and 1 mile south of the railroad the "Rockwood" formation is buried in a fault. Shallow workings are operated by hand in this area for the purpose of obtaining ore for the manufacture of metallic paint.

Soft ore was mined extensively at Hill City, at Inman, and near Ooltewah many years ago. Whether mining activities are ever renewed in these localities or elsewhere in Tennessee near Chattanooga will depend on future conditions in the iron industry. For the present ore to supply furnaces at Chattanooga will probably have to be obtained from areas farther north in Tennessee and from fields in northeastern Alabama and northwestern Georgia.

In the following table are given a few representative chemical analyses of iron ore from several localities in southeast Tennessee:

Analyses of "Rockwood" iron ore in southeast Tennessee.[a]

Locality.	Authority.[b]	Fe.	SiO_2.	Al_2O_3.	CaO.	MgO.	Mn.	P.	S.	H_2O.
2 miles north of Wauhatchie	U. S.	15.62	......	......	......	......	......	......	......	......
Hill City, upper bench	U. S.	27.30	6.21	3.20	26.53		0.056	0.52 (P_2O_5)	0.068	......
Hill City, lower bench	U. S.	17.27	......	......	......	......	......	......	......	......
Hill City	R.	25.00	[c]11. +		......	......	......	......	......	......
Hill City, near Workhouse	U. S.	29.92	[c]3.30		26.94	......	.10	.35	.04	......
Hill City (soft ore)	R.	45. +	[c]24. +	......	......	......	......	......	......	......
Do	R.	37.86	[c]22.23	......	......	......	......	......	......	......
Do	O.	57.5	10.26	1.61	.50	......	.46	.432	......	3.45
Falling Waters Creek, middle bed 13 inches thick	U. S.	12.53	......	......	......	......	......	......	......	......
2½ miles northwest of Hickson	U. S.	18.85	......	......	......	......	......	......	......	......
1 mile north of Retro	U. S.	19.92	[c]9.45		32.66	......	......	......	......	......
Ooltewah (soft ore)	B.	56.00	16.45	......	......	......	......	.28	.10	......
Do	B.	48.36	14.78	......	......	......	......	.63	......	......
Inman	B.	27.93	7.07	......	18.11	......	......	2.82	......	......

[a] Analyses represent hard ore unless otherwise indicated.
[b] Authorities: U. S., U. S. Geol. Survey; R., Roane Iron Co.; O., owners; B., W. M. Bowron.
[c] Insoluble.

CENTRAL EAST TENNESSEE.

Central east Tennessee contains large areas of iron ore and is at present the most productive portion of the State. Along the Cumberland escarpment between Sheffield and Glen Alice there are generally two thin seams of ore, the thicker of which measures less than 2 feet in some places and more than 2 feet in others, but in the vicinity of Glen Alice its thickness increases, and thence northeastward past Rockwood and Cardiff to Emory Gap the bed is normally from 2½ to 4 feet thick and in places reaches a maximum of 8 feet. The "Rockwood" formation received its name from the exposures at the town of Rockwood. The ore here is of comparatively high grade, the hard ore commonly carrying 35 to 42 per cent of metallic iron, 6 to 12 per cent of silica, 4 to 8 per cent of alumina, 10 to 15 per cent of lime, 1.5 to 4 per cent of magnesia, 0.5 to 0.6 per cent of phosphorus, and from a trace to 1 per cent of sulphur. The largest underground iron mines in the State are in the Rockwood-Cardiff area. Near Emory Gap the continuity of the bed is broken by a fault, but near Harriman a measurement showed 2 feet 4 inches of soft ore. From a point near Harriman northeastward to Coal Creek the outcrops of "Rockwood" ore are broken by several faults, and the thickness of the bed is from a few inches to about 2 feet.

Certain of the valley areas of central east Tennessee contain important reserves of "Rockwood" iron ore. In the Euchee area the bed is more than 5 feet thick, but the ore is lean. In the Chamberlain-Barnardsville area are two synclinal basins of ore that will furnish a supply to the Roane furnaces for many years. From 5 to 8 feet of hard ore of fair grade occurs here in two benches separated by a shale parting, and there is still available considerable rich soft ore.

The accompanying chemical analyses will afford a fairly definite idea of the quality of the ore available in central east Tennessee.

Analyses of "Rockwood" ore in central east Tennessee.

Locality.	Authority.[b]	Fe.	SiO_2.	Al_2O_3.	CaO.	MgO.	Mn.	P.	S.	H_2O.
Rockwood-Cardiff:										
Baker slope	R.	39.25	6.46	4.28	11.60	3.16	......	......	0.08	......
Do	R.	35.19	7.81	5.38	13.69	3.19	......	......	.220	......
Warner slope	R.	38.00	7.51	5.95	10.85	4.23	......	......	.124	......
Dyke slope	R.	37.00	8.92	8.11	9.76	3.42	......	......	.226	......
Do	R.	42.63	3.85	6.74	8.74	2.70	......	......	.160	......
Cardiff slope	R.	35.60	10.46	5.70	10.90	......	0.15	0.59	.08	......
Do	R.	42.90	6.00	5.56	9.39	2.66	......	......	Trace.	......
Wright slope	R.	26.10	6.11	6.51	20.43	......	......	......	......	......
Do	R.	35.10	8.08	5.27	14.00	2.59	.15	.60	.84	......
Howard slope	R.	33.35	15.35	8.60	6.88	......	.15	.60	.15	3.92
Do	R.	41.30	9.55	5.60	9.24	......	......	.127		......
Suddath slope	R.	34.65	6.85	4.01	17.11	2.80	.36	.07		......
Do	R.	36.13	5.81	3.83	16.66	2.57	......	.083		......
Patton slope	R.	41.82	8.05	3.30	9.47	3.39	......	.020		......
Do	R.	38.16	8.45	6.45	10.90	4.07	......	.030		......
Durel slope (soft ore)	R.	47.27	13.10	6.70	......	......	......	......	......	......
Do	R.	48.30	9.75	6.20	......	......	......	......	......	......
Ironton	C.	26.97	7.52	4:50	23.92	1.73	.35	......	.042	......
Do	C.	24.25	10.65	6.63	22.50	1.65	......	......	......	......
Do	C.	30.14	4.30	3.50	23.68	......	......	......	......	......
Glen Alice (soft ore, surface)	R.	50.19	12.58	9.82	1.15	......	.92	......	Trace.	......
Euchee:										
Crescent slope	D.	26.50	9.10	6.28	22.25	1.43	......	.416	......	......
Do	D.	32.00	7.69	5.58	18.45	1.48	......	.446	......	......
River mines (soft ore)	D.	45.80	11.72	7.10	......	......	......	......	......	......
Do	D.	47.40	14.76	8.70	......	......	......	......	......	......
Chamberlain	R.	25.20	3.48	3.25	25.15	1.84	......	......	......	......
Do	U.S.	36.30	7.92	3.07	13.77	1.71	.25	.57	.05	6.11
Do	U.S.	28.20	5.00	2.82	24.84	1.63	.23	.431	.05	5.61
Chamberlain (soft ore)	U.S.	52.45	7.62	4.31	.40	.47	.23	.532	.02	10.01
Do	U.S.	49.76	7.63	3.64	1.68	.50	.44	.736	.07	8.99

[a] Analyses represent hard ore unless otherwise marked.
[b] Authorities: C, Citico Blast Furnace Co.; D, Dayton Coal & Iron Co.; R, Roane Iron Co.; U. S., U. S. Geological Survey.

NORTHEAST TENNESSEE.

The "Rockwood" iron ore outcrops in one continuous strip at the foot of the Cumberland escarpment in northeast Tennessee from Caryville northeastward to Cumberland Gap, a distance of about 37 miles. The iron mines at La Follette and near Arthur are in this strip. The "Rockwood" ore outcrops also in the valley of Elk Creek for a distance of about 5 miles southwestward from the town of Elk Valley and probably extends from one valley to the other below the Cumberland Plateau.

The ore bed near Caryville measures 2 feet 10 inches in thickness, at La Follette it ranges from 3 feet 10 inches to 5 feet, and at the Watts mine near Arthur, 6 miles southwest of Cumberland Gap, the thickness is between 4 and 5 feet. There is a considerable strip northeast and southwest of the Watts mine with regard to which no data were obtainable during this survey. Southwest of the Watts mine, in the northwestern part of the Maynardville quadrangle, the outcrop of the "Rockwood" formation is so far from a railroad that little prospecting has been done. Southwest of the town of Elk Valley the ore bed reaches a maximum thickness of 4 feet. The outcrop in Elk Valley is badly broken by faults. It is possible that there is a basin of ore 1,500 feet to 3,000 feet below the Cumberland Plateau extending from La Follette to Elk Valley; if so, there is a vast reserve of hard ore in this area, aggregating 1,250,000,000 long tons, but this can hardly be considered as available under present conditions on account of its depth. Mining is at present active at La Follette, on the "vertical" ore bed.

The following chemical analyses indicate the quality of the "Rockwood" iron ore in northeast Tennessee:

Analyses of "Rockwood" iron ores in northeast Tennessee.[a]

Locality.	Authority.[b]	Fe.	SiO_2.	Al_2O_3.	CaO.	Mn.	P.	S.	H_2O.
La Follette:									
Seneca mine	L	26.3	10.24	8.30	15.89	0.60	0.61	0.0	5.0
Do	L	31.90	4.54	2.57	15.25	......	......	......	......
Do	L	[c]36.40	[d]7.82		13.30	......	.48	......	......
Soft ore	L	[c]44.65	12.48	......	......	......	......	......	15.32
Do	L	[e]38.89	12.39	6.54	3.10	......	.684	......	......
Near Loyston (soft ore)	O	48.2	8.9	11.0	......	.36	......	......	......
Near Millers Ferry (soft ore)	O	50.4	5.6	......	......	......	.04	......	.5

[a] Analyses represent hard ore unless otherwise indicated.
[b] Authorities: L, La Follette Coal, Iron & Railway Co. and La Follette Iron Co.; O, owners of property.
[c] Dry basis.
[d] Insoluble.
[e] Wet basis.

NORTHEAST ALABAMA.

GENERAL DISTRIBUTION OF ORE OUTCROPS.

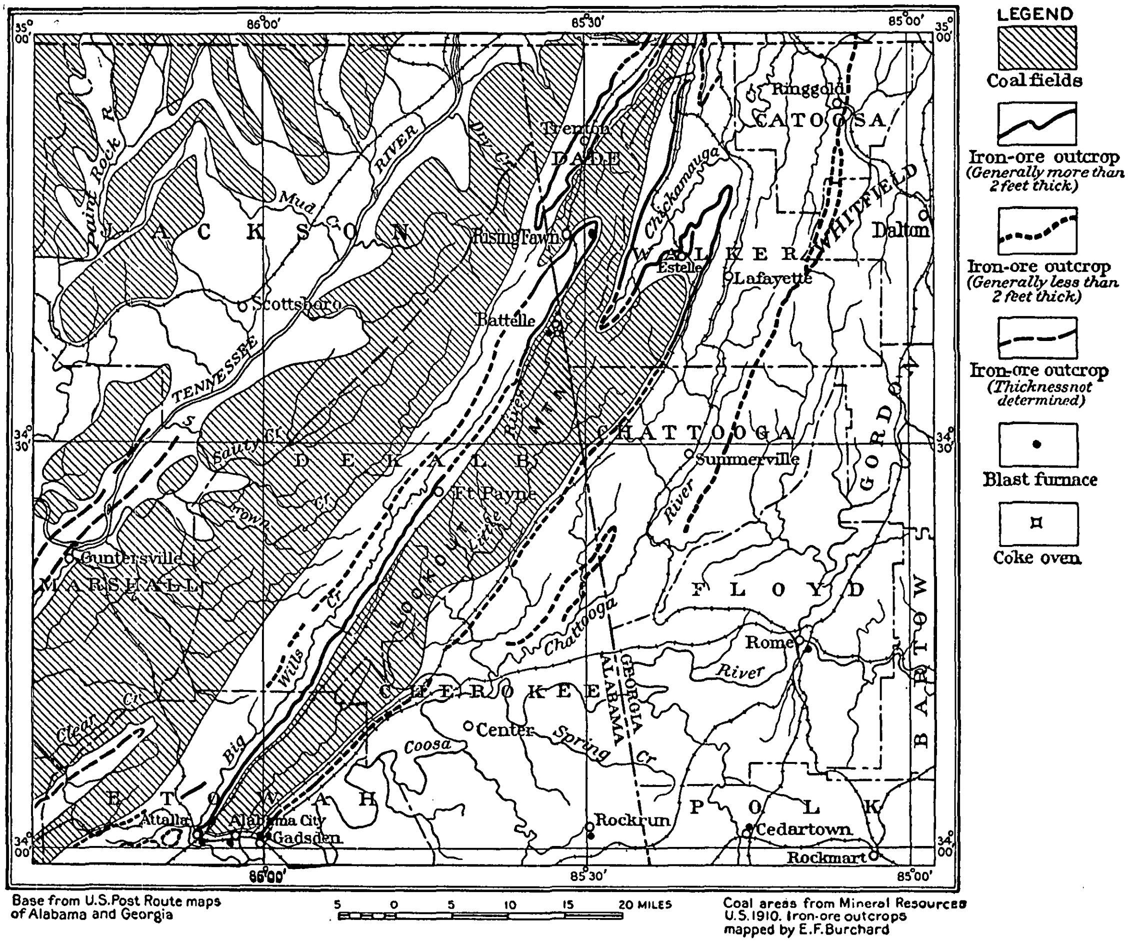
The area of "Rockwood" iron ore in northeast Alabama extends from Attalla and Gadsden, Ala., northeastward to the Alabama-Georgia line. (See Pl. VI.) The ore-bearing "Rockwood" formation, which probably underlies the greater part of the Lookout Mountain syncline, outcrops, except where cut out by faults, along the northwest and southeast borders of the mountain.

Northeast from Attalla the ore bed outcrops in a low ridge called Red Mountain that extends parallel to the northwest base of Lookout Mountain at a distance of 1 to 1½ miles. The dips are here toward the southeast. On the opposite or northwest side of Wills Valley the ore bed outcrops with steep northwest dips except where it has been overturned or interrupted by faults. This outcrop approximately parallels the Red Mountain outcrop at a distance of about 3½ miles. Wills Valley extends along the axis of an anticline in which the ore beds and associated rocks dip away toward the synclinal basins of Lookout Mountain and Sand or Raccoon Mountain. The Alabama Great Southern Railroad passes along a narrow valley between the west border of Lookout Mountain and Red Mountain and is nearly everywhere within about a mile of the outcrop of the ore bed in Red Mountain.

Along the southwest end of Lookout Mountain between Attalla and Gadsden the outcrop of the "Rockwood" ore is cut off by a fault. From Gadsden northeastward the ore outcrops for about 20 miles in Shinbone Ridge nearly to Yellow Creek, where it is cut off by a fault that interrupts the outcrop for a distance of about 2½ miles. Near Sterling Gap the ore reappears in the section, and it may be traced thence almost continuously northeastward in Shinbone Ridge to the Alabama-Georgia line, a distance of 19 miles. The Shinbone Ridge outcrop represents the southeast limb of the Lookout Mountain syncline. The dips here are generally steep toward the northwest, or they may be overturned toward the southeast. The Tennessee, Alabama & Georgia Railroad traverses the narrow valley between Lookout Mountain and Shinbone Ridge and is nearly everywhere between a quarter and half a mile from the ore outcrop.

The only other "Rockwood" ore-bearing locality in this portion of northeast Alabama remaining to be mentioned lies north of Coosa River, in a ridge known in the southwest portion as Tucker Ridge and in the northeast portion, which extends into Georgia, as Dirtseller Mountain. Round Mountain, a small outlier of Tucker Ridge, also carries "Rockwood" ore. The outcrop of the ore bed in Tucker Ridge dips moderately to the southeast, forming one side of a narrow synclinal basin whose axis rises to the northeast and which extends in a northeast-southwest direction for about 12 miles. For about half that distance this outcrop is closely paralleled by a lower ridge carrying ore dipping northwest and representing the southeast edge of the syncline. The Rome & Attalla branch of the Southern Railway passes south of this area, the station of Cedar Bluff being about 3 miles from the nearest ore outcrop on Tucker Ridge. This ore-bearing area has been known also by the terms "Gaylesville area" and "Mill Creek area," on account of the proximity of the town and creek so named.

The areas of "Rockwood" iron ore in northeast Alabama, outlined above, lie principally in the Fort Payne quadrangle, although the southwest extremity of the ore-bearing region extends a few miles into the Gadsden quadrangle and the northeast portion extends a few miles into the Stevenson and Rome quadrangles. The United States Geological Survey sells topographic maps of all these quadrangles.



MAP SHOWING RELATION OF OUTCROPS OF RED IRON ORE TO COAL FIELDS, TRANSPORTATION ROUTES, AND INDUSTRIAL CENTERS IN NORTHEAST ALABAMA AND NORTHWEST GEORGIA.

WILLS VALLEY.

The thickness and quality of the ore beds exposed in Wills Valley vary greatly from place to place. For the most part the bed in Red Mountain from Attalla northeast to the State line is more than 2 feet thick, and in places it is as much as 5 feet. The following thicknesses were noted during recent examinations of the ore: At Attalla, 2½ to 3½ feet; at Crudup, 2½ to 5 feet; at Keener, 1¼ to 2½ feet; at Collinsville, where some of it is shaly ore, 1½ to 4 feet; at Portersville, 3 to 4½ feet, with a shale parting 8 inches to 1½ feet thick; at Collbran, 3 feet 9 inches to 4 feet, including 1¼ feet of shaly ore and shale partings; at Fort Payne, 3 to 3½ feet; near Valley Head, 1 foot 3 inches to 1 foot 6 inches; at Battelle, 4 to 4½ feet (upper bed) with three thinner beds below. The dips are mostly between 15° and 30° SE., and the variations are generally gradual rather than abrupt.

On the west limb of the Wills Valley anticline there has been but little development of the "Rockwood" iron ore, for several reasons. (1) The ore is thinner than on the east limb of the anticline, probably averaging less than 2 feet thick where exposed; (2) it is generally in a much steeper position and faulting has broken it badly in places and buried it deeply, especially in the southwestern portion of the area; and (3) the distance from the railroad, 3 to 4 miles, is too long to haul much ore or to build a railroad spur unless an extensive deposit is to be tapped. Near Littleton, where the bed is overturned to the southeast, thicknesses ranging from 1½ to 2½ feet have been measured. At the northeast end of the area, near Sulphur Springs, the main ore bed is 2 feet 5 inches to 4 feet thick, but includes several shale partings, so that there is not more than 2 feet 9 inches of ore. The ore bed here dips about 50° NW. The anticline on whose margins these ore beds outcrop extends northeastward into Georgia and the axis plunges under Lookout Mountain in Johnson Crook, east of Rising Fawn.

PUDDING RIDGE.

About 10 miles north of Battelle is situated the Pudding Ridge belt, only about 1½ miles of which lies in Alabama. This is a promising ore-bearing area that is mentioned also in the Georgia descriptions (p. 308). Pudding Ridge lies in the axis of an anticline at the head of Lookout Valley. The "Rockwood" ore crops out on each side of this valley and around the end of the anticline at Pudding Ridge. Several prospects have been made in Alabama in hard ore that was 2½ to 3¼ feet thick exclusive of a few thin shale partings.

SHINBONE RIDGE.

Beginning at Gadsden and extending northeastward the "Rockwood" ore that outcrops in Shinbone Ridge shows a variable but progressive deterioration in both thickness and quality. Near Gadsden the ore is about 4 feet thick, but within 2½ miles it thins to 1 foot 8 inches. Near Gadsden the dip is steep to the northwest. Between 5 and 8 miles from Gadsden, in the vicinity of the Citico mines, the thickness of the ore ranges between 2 and 3 feet and the dip is less steep, ranging from 30° to 40° NW. The hard ore is limy and lean and the ore bed contains many kidney-shaped concretions of shale. In the next 5 miles the ore bed thins down to about 5 inches, then thickens northeastward, and opposite Slackland the section includes three seams of very sandy ore or ferruginous sandstone ranging from 1 foot to 2 feet in thickness. Here the beds stand nearly vertical. Near Bristow the "Rockwood" formation comprises eight seams of very sandy ore from 1 inch to 10 inches thick, parted by beds of shale 6 inches to 46 feet thick. The dip here is about 65° SE. Beyond Bristow measurements of 5 to 7 inches were made and the dips are 35°–40° NW. About 3 miles northeast of Bristow the "Rockwood" formation is cut out by a fault, but it reappears beyond, at a distance of about 2½ miles. From Starling Gap northeastward to the State line the greatest observed thickness of good ore was 1 foot, but in places the seam contains a few inches more of sandy and shaly ore. About a mile northeast of Taff there are within a section of 28 feet 3 inches 27 seams of poor sandy ore, ranging from 1 inch to 1 foot 3 inches in thickness, separated by shale. The dips in this part of Shinbone Ridge are toward the southeast, indicating that the ore bed has been completely overturned. Farther northeast, near Jamestown and beyond, the dips are generally 35°–40° NW. A measurement made about a mile from the State line showed 8 inches of iron ore.

TUCKER RIDGE (DIRTSELLER MOUNTAIN).

Northwest of Gaylesville, in Tucker Ridge, the ore bed ranges between 6 inches and 2 feet 2 inches in thickness and dips generally 15°–35° SE. It is in most places parted by thin seams of shale. There is probably some soft ore here that may be obtained by stripping, but if not, the bed can not be considered of commercial value. On the southeast limb of the syncline, near Mill Creek, the bed shows 1 foot to 1 foot 10 inches of ore, dipping 45°–48° NW.

ROUND MOUNTAIN.

In the small isolated hill known as Round Mountain, near the Southern Railway, about 3 miles southwest of the extremity of Tucker Ridge, a thin bed of "Rockwood" ore occurs. This bed varies in thickness from 1 foot to 2 feet 4 inches. The dips are also diverse. The ore on the outcrop is soft and has been mined on the surface and from short drifts, but has since been mostly obscured by slumping of the overlying shale.

MINING.

The "Rockwood" ore has been mined at many places in northeastern Alabama, both west and east of Lookout Mountain. Stripping for soft ore has mostly been abandoned, and underground mines have been opened wherever the thickness and character of the ore beds appeared to warrant it. In Red Mountain there are two mines near Attalla, two near Crudup, and abandoned slopes near Portersville, Fort Payne, and Battelle. In Shinbone Ridge there are several slopes near Gadsden and an inactive mine (the Citico) about 7 miles northeast of Gadsden. Near Mill Creek, in the Dirtseller, syncline ore has been mined by stripping and from shallow drifts, and at Round Mountain the soft ores were mined many years ago to supply an old charcoal furnace.

The ore mined at Attalla is shipped to Chattanooga and also to local furnaces at Attalla and Gadsden. Crudup ore and Gadsden ore are reduced in blast furnaces at Gadsden, and when mining was carried on in the Dirtseller area the ore was shipped both to Chattanooga and to Gadsden.

ANALYSES.

The following analyses show the character of the iron ore in northeast Alabama:

Analyses of "Rockwood" iron ore from northeast Alabama.[a]

Locality.	Authority.[b]	Fe.	SiO_2.	Al_2O_3.	CaO.	MgO.	Mn.	P.	S.	H_2O.
Attalla	C.	36.97	8.61		16.56			0.50		
Do	C.	40.65	11.36	4.86	11.36		0.18	.44		
Attalla (soft ore)	A.	53.92	8.39					.676		
Crudup (south)	S.	35.80	13.94	5.07	15.34					
Crudup (north)	S.	38.14	9.29	3.87	17.01					
Keener	S.	25.60	12.50	5.37	22.34		.26	.35		
Portersville (average)	S.	31.98	6.29		24.80					
Collbran	U. S.	20.85	6.89	1.10	30.21					
Fort Payne	O.	25.39	4.11		30.13			.34		
Do	O.	26.41	3.97		29.80			.375		
Fort Payne (soft ore)	O.	56.02	7.93		n. d.			.227		
Battelle (drill hole)	B.	32.26	4.52	2.93	24.33					
Battelle (average hard ore)	L.	27.65	4.70	3.90	25.15	0.73		.376		0.48
Gadsden	S.	33.07	16.82	8.29	14.00					
Citico (7 miles northeast of Gadsden)	C.	38.07	10.24	4.17	14.38	1.16	.14	.38		
Do	C.	38.50	13.16		12.75					
Citico (soft ore)	C.	54.87	8.05							
4 miles northwest of Gaylesville (soft ore)	U. S.	55.39	[c]12.25		1.16		Tr.	.59	0.08	

[a] Analyses represent hard ore unless otherwise indicated.
[b] Authorities: A, Alabama Geological Survey; B, W. M. Bowron; C, Citico Blast Furnace Co.; L, Lookout Mountain Iron Co.; O, owner of property; S, Southern Iron & Steel Co.; U. S., U. S. Geological Survey.
[c] Insoluble.

NORTHWEST GEORGIA.

GENERAL DISTRIBUTION OF ORE OUTCROPS.

Most of the outcrops of "Rockwood" iron ore in northwest Georgia are direct continuations of the outcrops in Alabama just outlined. (See Pl. VI.) On both sides of Lookout Valley they are continuous from Pudding Ridge to a point beyond the Tennessee line, the eastern outcrop dipping under Lookout Mountain and the western outcrop dipping below Sand Mountain. The Wills Valley outcrops end in Johnson Crook, where the "Rockwood" strata are exposed around the nose of the anticline. On the east side of Lookout Mountain the Shinbone Ridge outcrop extends northeastward to the extremity of Pigeon Mountain, around the end of that mountain into McLamore Cove, and thence northeastward on the east flank of Lookout Mountain and terminates in a fault near Flintstone, $2\frac{3}{4}$ miles south of the Tennessee line. The Tucker Ridge and Dirtseller outcrop continues northeastward into the Dirtseller synclinal area, which terminates about 2 miles west of Lyerly, Ga., and shows two outcrops of ore that converge and unite at the end of the syncline. In addition to these outcrop areas the "Rockwood" formation in Taylor Ridge carries beds of iron ore, which are thickest in the locality between Summerville and Gore, but a very thin bed may be traced northeastward to the Tennessee line into the Whiteoak Mountain area. According to McCallie[1] the length of outcrop of the "Rockwood" iron ore in Georgia aggregates about 175 miles, and, if the trace of the outcrops above described is scaled off on the map, the aggregate length may even be found to exceed that figure, but for a considerable part of the distance the ore is too thin to be of commercial value. These areas are comprised within the Stevenson, Ringgold, Fort Payne, and Rome quadrangles. For more detailed descriptions of ore outcrops and sections in northwest Georgia the reader is referred to the bulletin by McCallie, just cited. Brief descriptions of the principal areas are given below.

LOOKOUT VALLEY.

On both sides of Lookout Valley, from New England southwest to Pudding Ridge, and also for about 2 miles northeast of New England, on the east side of the valley, the ore beds appear to be of considerable value. The soft ore has been worked at many places in this area, and the bed of hard ore has thus been made available for measurement. The general range in thickness of ore, exclusive of shale partings, is from 2 feet 5 inches to 3 feet, although in places the bed is slightly thinner and in places it attains a thickness of

[1] McCallie, S. W., The fossil iron ores of Georgia: Bull. Georgia Geol. Survey No. 17, 1908, p. 39.

nearly 4 feet. Locally there are two ore beds of about the same thickness in the section, but as a rule only one bed is of importance. In one place near the Alabama-Georgia line, where a thickness of nearly 6 feet is displayed with an 18-inch shale parting, the bed has doubtless been repeated by a small thrust fault. The ore in the area mentioned above is generally high in lime and could be used most advantageously in connection with an ore carrying considerable silica, such as a soft red ore, a siliceous hard red ore, or a brown ore. There is still some soft red ore available in this area. The dips of the beds on either side of the anticline are moderate toward the northwest or the southeast, as the case may be, ranging generally between 10° and 30°.

The outcrop on the east side of the valley is generally within a mile of the Alabama Great Southern Railroad. From the west side of the valley there would be longer hauls, but railroad spurs could be built to reach the ore outcrops at most places. The ore generally crops out at 100 to 200 feet above the valley floor, so that considerable ore can still be mined without involving much hoisting.

JOHNSON CROOK.

From Sulphur Springs station to Johnson Crook the "Rockwood" formation outcrops for a distance of about 8 miles on the southeast side of the anticline and about 6 miles on the northwest side, all within the State of Georgia. Little information is available concerning the character of the ore in this area except in Johnson Crook, where it has been mined for use in the old blast furnace 1 mile east of Rising Fawn. There are three or more seams of ore here, two of which are too thin to be worked and one carries 3 feet 8 inches to 5 feet of ore. This thickest seam contains one or two shale partings, from 3 to 15 inches thick. The ore in this seam, where hard, is high in lime and low in iron, as shown in the analyses on page 42. The workings in the soft ore at this place were formerly very extensive and a few short underground slopes have been driven, but not much ore has been mined since 1906. The ore-bearing beds dip, generally at a moderate angle, toward the north, northeast, and east into the Lookout Mountain syncline, from which they emerge again in McLamore Cove, 3½ miles distant.

MENLO TO BRONCHO.

On the east side of Lookout Mountain the Shinbone Ridge outcrop continues northeastward into Georgia. The beds are nearly everywhere steeply inclined at the outcrop, but the normal dip, which is toward the northwest, is reported to become more gentle within 100 feet below the surface. The thickness of the ore in this strip of outcrop from the State line 1½ miles southwest of Menlo to a point above Broncho ranges from less than 1 foot to about 3 feet, exclusive of shale partings. The ore on the outcrop is soft, and probably the leached condition of the ore extends deeper here than in places where the dip is less steep. The Tennessee, Alabama & Georgia Railroad runs nearly parallel to the ore outcrop at a distance of 1,000 to 1,500 feet and has afforded convenient facilities for shipment of ore to Chattanooga and Gadsden, so that soft ore has been mined from open cuts all along the outcrop. A little mining has been done also by means of slopes and drifts. One slope at Broncho is reported to have been sunk 204 feet in soft ore.

PIGEON MOUNTAIN.

Pigeon Mountain is a spur extending northeastward from Lookout Mountain in the southern part of Walker County, Ga. Its rock structure is synclinal, the formations outcropping around the base of the mountain and dipping toward its axis. At Estelle the ore dips in general to the south and southeast. At the northeast end of the mountain, west of Copeland, the rock lies nearly flat, and where the ore-bearing formation outcrops around the southeast side of the ridge the dips are toward the west and northwest.

Near Estelle, for about 1 mile to the northeast and about 3 miles to the southwest of the Tennessee, Alabama & Georgia Railroad, the ore has been mined to a considerable extent on the outcrop and also from a number of drifts and tunnels. This area has been a large producer of soft ore in the past, most of it having been shipped to the furnaces at Chattanooga and La Follette, Tenn. Three beds of ore occur just below the middle of the "Rockwood" formation. They are about 25 feet apart, but only the lowest bed, which is 2½ feet or more thick, can be considered of great importance. One of the upper beds has been stripped for soft ore over a considerable area. In some places it is 1 foot 9 inches thick, including a shale parting that has a thickness ranging from a knife-edge up to 2 inches.

The large scale on which mining operations have been carried on in the vicinity of Estelle is due in great part to the fortunate relation between the ore bed and the local topography. A chain of hills, not well shown on the topographic map of the Ringgold quadrangle, extends parallel to the northwest side of Pigeon Mountain, from which it is separated by a long hollow. This chain of hills is cut transversely by numerous small hollows that open into the main hollow. The strata emerging from beneath Pigeon Mountain extend upward into the chain of hills at nearly the same angle as the surface slope of the hills. The bed of iron ore is so close to the surface in many places that the overburden may be stripped off and the ore mined in the open. The small hollows that cut the hills transversely afford favorable positions for opening entries into the ore bed and for laying tracks. The comparatively small thickness of cover has permitted the access of surface water to the ore bed in much of the area and thus produced considerable soft ore.

With regard to reserves of hard ore in the area near Estelle there appear to be encouraging possibilities. Beginning near the tunnel of the Tennessee, Alabama & Georgia Railroad and extending in a southwesterly direction for several miles there is a bed of semihard to hard ore of excellent quality dipping gently under Pigeon Mountain. This bed reaches 2 feet 9 inches in thickness in places and is generally more than 2 feet 6 inches thick. It commonly includes a shale parting 1 inch to 1½ inches thick just below the middle and is overlain by hard fine-grained sandstone or "jack rock." The dip at the outcrop ranges between 2° and 10° SE., but is generally 6° or 7°. The beds probably lie nearly flat under most of Pigeon Mountain, but near the southeastern outcrop they are thrown into a series of sharp folds. From the railroad tunnel southeastward to the outcrop on the southeast side of Pigeon Mountain the shortest distance is about 1½ miles, and there is no reason to doubt that the whole basin is underlain by this bed of iron ore. Analyses of this ore given on page 42 show that it is a very high grade hard ore.

Mining would necessarily have to be carried on here by underground work, but the apparent regularity of structure of the ore bed, the proximity of the railroad, and the excellent quality of the ore make it very probable that ore could be mined and loaded on railroad cars at a reasonable cost per unit of iron. In connection with the mining of soft ore from open cuts in the vicinity of Estelle some hard ore has also been mined from underground workings, and even during the summer of 1911, when the price of southern pig iron was only about $10 a ton, hard ore was steadily shipped from a small mine near Estelle.

The iron-ore outcropping on the southeast side of Pigeo[illegible] tain, nearly opposite Estelle, has been most recently mine[illegible] dale. Here the strata dip steeply toward Pigeon Mo[illegible] the main line of outcrop of the ore bed, but east of th[illegible] beds have been folded so as to produce in connection [illegible] surface two small truncated synclines of ore. A sing[illegible] shows five outcrops in a cross section of only a few [illegible] length, and it was at one time believed that there w[illegible] seams of ore here, all of about the same thickness, [illegible] seam, too thin to work, is reported to lie 8 to 10 feet seam. A number of measurements at the mines that were in operation in 1911 showed a range in thickness of the main ore bed of 1 foot to 2 feet, though 1 foot 8 inches to 1 foot 10 inches appeared to be the general range. The seam contains no shale parting. The ore being mined in the fall of 1911 was obtained principally from drifts and shallow slopes, and it was reported that the soft ore continued to depths of 50 feet or more. The ore being shipped was a high-grade soft ore carrying 50 to 57 per cent of iron. On account of the folding of the strata the "spread" of the ore renders available an unusually large quantity of soft ore. Shipments were made in 1911 to blast furnaces at Dayton and La Follette, Tenn.

At the northeast end of the Pigeon Mountain syncline, about 2¼ miles west of Copeland and about 5 miles northeast of the Estelle mines, the "Rockwood" formation occupies a relatively broad outcrop area in which the rocks lie nearly horizontal. The surface consists of knobby hills and narrow ravines, around and into which the iron-ore outcrop winds in sinuous curves. There are two or three beds of ore in this area, the thicker ones carrying between 2 and 4 feet of ore parted by two to five seams of shale varying from less than 1 inch to 1½ feet in thickness. In certain places where the ore is well exposed it is soft and fairly rich in iron, but in many of the outcrops on the sides of ravines the hard ore shows at the surface and apparently is highly calcareous and consequently correspondingly lean in iron. On account of the large proportion of shale that is interbedded with the ore and would have to be mined with it, the grade of the ore would probably be materially improved by crushing, screening, and picking to remove the shale.

It is reported that a railway spur was built and mining operations were begun in this area a few years ago but were soon abandoned.

McLAMORE COVE TO FLINTSTONE.

Southwest of Bluebird Gap on the east side of McLamore Cove, or southwest of the Estelle mine workings, the ore beds become shaly and sandy and in places very thin—in fact, the ore does not appear [illegible] of much importance anywhere on the borders of McLamore [illegible]outh of an east-west line drawn through Cedar Grove, although [illegible]ockwood" formation outcrops all the way around the cove. [illegible]tward from Cedar Grove the outcrop of the ore-bearing [illegible] extends unbroken for 16 miles to a point near Flintstone, [illegible] terminates in a fault. Throughout this strip of outcrop [illegible] nearly everywhere steeply tilted to the northwest or over[illegible]he southeast, and there are in places minor synclines of [illegible]e main outcrop. Near the church south of Cedar Grove [illegible] foot 7½ inches thick was measured, and west of the village of Cedar Grove there are two seams, each 1 foot thick, showing an anticlinal structure.

From Cedar Grove to Cassandra the ore bed ranges between 1 foot and 1 foot 10 inches in thickness. In some of the exposures noted the bed contains several shale partings. About a mile north of Cassandra the bed becomes thicker, 3 feet being measured in one place, and a thickness between 2 feet 6 inches and 3 feet is apparently maintained nearly all the way to Eagle Cliff. Near Eagle Cliff measurements of the ore bed showed a variation in thickness of 1 foot 9 inches to 3 feet, and near Flintstone of 1 foot 8 inches to 2 feet 6 inches. Soft ore has been mined nearly all the way along the outcrop where the ore bed is thickest. From Cassandra northward the Tennessee, Alabama & Georgia Railroad is generally within one-fourth to three-fourths of a mile from the ore outcrop. Very little mining has been carried on here during the last seven or eight years.

MISSIONARY RIDGE AND VICINITY.

The "Rockwood" formation outcrops in Missionary Ridge for a distance of about 2½ miles southwest from McFarland Gap, in the northern part of Walker County. At the southwest extremity of this strip the outcrop of the formation turns abruptly toward the north, following a low ridge, and extends to and beyond the Tennessee-Georgia line, the two outcrops forming a V-shaped area bordered by faults. The Tennessee, Alabama & Georgia Railroad is within a mile of the west outcrop at one place, and the Central of Georgia Railway touches it at McFarland Gap.

The ore in Missionary Ridge ranges in thickness from 1 foot 6 inches to 2 feet 6 inches and dips to the southeast at angles from a few degrees to 40°. The ore bed is generally parted by 1 to 2 inches of shale. The bed has been stripped and mined on the outcrop so as to reach the hard ore in several places, as much as 15 feet of cover having been removed. The hard ore is high in calcium carbonate and not very rich in iron, but the soft ore, although little probably remains available, is of high grade.

In the western ridge the ore is 1 foot 10 inches to 2 feet 7 inches thick near the State line, less than 2 feet thick near the south end, and still thinner at an intermediate place. This bed dips generally 15°–35° W., but toward the south end of the strip the angles are steeper. Soft ore has been dug at many places along this outcrop, hauled by wagon to the Tennessee, Alabama & Georgia Railroad, and shipped to furnaces at Chattanooga and Dayton, Tenn.

It should be noted in this connection that the extent of the ore in the direction of the dip in both strips of the V-shaped area is limited by faults, and according to the Ringgold geologic folio map the ore probably does not extend underground more than 500 to 700 feet, except near the State line, where the fault disappears.

DIRTSELLER MOUNTAIN.

At the north end of Dirtseller Mountain, 2 to 3 miles southwest of Lyerly, Ga., red ore has been obtained from surface workings for many years. The structure of the Dirtseller Mountain "Rockwood" area is synclinal, the ore dipping southeastward from the crest of the ridge toward Panther Creek and rising again farther southeast to form the crest of a lower ridge. The synclinal axis rises to the northeast, so that the ore outcrops around the end of the syncline at a point about 2 miles west of Lyerly. The dips of the beds and the slopes of the sides of Panther Creek valley are very nearly the same, and the ore bed is overlain, for the most part, by a comparatively thin cover, so that it has been possible to strip the ore for several miles along its outcrop and for several hundred feet on the dip. A large tonnage of soft ore has been obtained here and shipped to furnaces at Rome, Ga., and Attalla, Ala. Most of the ore has been mined by means of stripping, but a little underground work has been done from drifts and tunnels. No mining is being done here at present.

The thickness of the ore bed ranges from 1 foot 2 inches to 2 feet 4 inches. The maximum is exceptional and the average thickness perhaps does not exceed 1 foot 6 inches. In some places the bed is a solid body of ore; in others it is parted by shale seams. The dips of the bed toward the synclinal axis along which Panther Creek flows are low, ranging generally between 4° and 15°. Evidences of a second syncline of ore were noted a short distance southeast of the outcrop of the ore in the southeast limb of the main syncline. This appeared to be a shallow appressed fold, separated from the main syncline by erosion, and probably does not extend a great distance northeast and southwest. There is still sufficient ore remaining in the Dirtseller area to require many years for its exhaustion at the rate of output that prevailed during the days of mining activity. The unaltered ore in this area generally carries less lime and more silica than the ore in the Lookout Mountain area.

TAYLOR RIDGE.

Taylor Ridge, the southwestern portion of which lies about 3½ miles east of Summerville and Lyerly, extends northeastward to the Tennessee line and is part of the fold in the strata that produces Whiteoak Mountain in Tennessee. The only portion of the ridge that is of importance as a bearer of iron ore is the area southeast of Summerville. For about 4 miles along the ridge the ore in the thicker of two beds ranges from 1 foot 5 inches to 2 feet 5 inches in thickness. There is generally a parting of shale 2 inches to 3½ feet thick below the middle of the bed. The dip of the ore bed ranges generally from 12° to 20° SE. The bed outcrops near the crest of the ridge and as its dip is only a little steeper than the southeast slope of the ridge, there is a large area of soft ore here. Considerable of the ore below the outcrop, especially at the sides of ravines that cut the flank of the ridge, may be obtained by open-cut mining. By drifting in the direction of the strike of the ore bed from both sides of the narrow ravines and working up the dip the ore can be cheaply mined underground. Both of these methods of mining have recently been employed by the R. G. Peters Mining Co., which operated mines just west of Shackelton for a year or so prior to 1911. Openings were made along several of the ravines and the ore was trammed in small cars to bins near the foot of each ravine. From the collecting bins the ore was fed into small steel cars or conveyors, which traveled on an aerial cable. In one place ore was carried from one hollow to another over an intervening spur. From the main collecting point the ore was carried by the aerial cable line to the Rome & Northern Railroad at Shackelton and thence by railroad to the blast furnace of the Silver Creek Furnace Co., at Rome. It is understood that the operation of the aerial tramway was not a complete success.

The soft ore mined here is dark colored and rather rich in iron. The hard ore resembles the Dirtseller ore in carrying less lime, more silica, and more iron than the ore of the Lookout basin.

Southwest of the Peters mine the "Rockwood" ore extends nearly to High Point, the southern terminus of Taylor Ridge, but the thickness of the bed diminishes to 8 or 10 inches near High Point. Northeastward from the Peters mine the ore has been traced, as stated above, practically all the way to a point beyond the Tennessee line, and for about 17 miles, partly in Walker County and partly in Whitfield County, there are two outcrops of the ore on the limbs of a narrow synclinal basin. Gordon Spring, Whitfield County, is situated near the middle of this syncline. A few miles northeast of the Peters mine the ore becomes much thinner than at this mine, and, except where the Western & Atlantic Railroad crosses the outcrop, about 1 mile east of Ringgold, the ore does not lie near any railroad. Measurements made at 20 or more places in 1911 showed seams of ore ranging from 1 inch to 1 foot 1 inch in thickness, though most of them were between 3½ and 10 inches. At one place north of Gordon Spring there were seven seams of ore from 1 inch to 5 inches thick within a section of 70 feet. In some places there is much float, and this has given rise to local belief in the presence of thicker seams than it has been possible to find.

ANALYSES.

The following chemical analyses exhibit the range in percentages of the various grades of ore:

Analyses of "Rockwood" iron ore from northwest Georgia.[a]

Locality.	Authority.[b]	Fe	SiO_2	Al_2O_3	CaO	MgO	Mn	P	S	H_2O
Rising Fawn	S.	26.47	9.00	3.88	25.13	......	......	......	......	......
Do	G.	33.76	7.28	3.14	21.41	0.44	0.216	0.51	Tr.	2.14
Pudding Ridge	O.	28.42	5.88	5.32	25.96	Tr.	......	2.14	Tr.	......
Do	G.	32.53	4.62	3.89	24.95	.40	.177	.572	0.10	1.02
Trenton	P.	36.85	......	......	18.15	......	......	......	......	......
Do	O.	28.79	5.62	2.86	25.73	......	......	.398	......	......
Do	O.	29.86	6.76	4.86	24.29	......	......	.324	Tr.	......
Do	O.	33.22	7.62	3.56	19.58	......	......	.422	......	......
New England	C.	28.01	c 9.50		......	......	......	......	......	......
Do	U. S.	29.27	4.66	1.36	30.65	......	......	......	......	......
Do	U. S.	26.16	7.07		27.18	......	.12	.21	.04	......
Do	O.	28.67	5.94	3.24	24.31	......	......	.393	......	......
Morganville	C.	29.54	7.81	......	......	......	......	......	......	......
Broncho (semihard)	G.	42.72	4.98	2.78	14.48	1.95	.447	.501	.06	.91
Estelle, Southern Iron & Steel Co. mines	G.	32.18	7.00	5.45	22.70	.59	.223	.42	.02	1.89
Do	G.	38.42	6.41	11.89	14.89	.16	.062	.56	.01	2.28
Estelle, Estelle Iron Co	O.	43.50	c 8.12		15.62	......	......	......	......	......
Do	O.	42.63	c 6.78		16.81	......	......	......	......	......
Estelle, Estelle Iron Co. (soft ore)	O.	57.87	c 9.58		.56	......	......	......	......	......
Estelle, Estelle Iron Co. (composite samples from several prospects)	U. S.	44.57	10.12	5.06	7.05	......	......	......	......	......
Do	U. S.	41.35	7.21	4.18	11.94	......	.062	.362	.099	......
Do	U. S.	43.85	6.74	2.89	11.11	......	......	......	......	......
Hillsdale (soft ore), northeast end Pigeon Mountain	LF.	48.70	15.80	6.40	.76	......	.30	.34	.10	.20
Cooper Heights (soft ore)	C.	43.08	19.67	9.15	.96	.56	.87	.32	......	......
Durham Junction	C.	32.38	8.24	......	21.52	......	......	......	......	......
Cenchatt	C.	25.95	c 19.54		19.42	......	......	......	......	......
Do	C.	32.76	17.38		15.80	......	......	......	......	......
Eagle Cliff (semihard)	D.	35.30	11.20	6.70	15.39	......	1.60	.453	......	......
Three-fourth mile east of Blowing Spring	U. S.	25.69	4.14	2.89	26.48	......	......	......	......	......
1¼ miles southwest of Mission Ridge station	U. S.	19.87	......	......	......	......	......	......	......	......
2 miles southwest of Mission Ridge station (soft ore)	U. S.	42.33	18.81	10.00	Tr.	......	......	......	......	......
Do	U. S.	48.94	13.95	6.85	Tr.	......	......	......	......	......
Dirtseller (nearly soft)	C.	47.00	15.75	4.60	2.70	......	......	......	......	......
Taylor Ridge, near Shackelton (soft)	C.	46.82	c 27.64		......	......	......	.64	......	......
Do	C.	52.10	c 21.50		......	......	......	.32	......	......
Do	C.	58.50	c 21.94		......	......	......	.61	......	......
Do	U. S.	48.01	c 22.14		1.65	......	......	......	......	......

[a] Analyses represent hard ore unless otherwise indicated.
[b] Authorities: C, Citico Blast Furnace Co.; D, Dayton Iron & Coal Co.; G, Geological Survey of Georgia; LF, La Follette Iron Co.; S, Southern Iron & Steel Co.; O, owner of property; U. S., U. S. Geological Survey.
[c] Insoluble.

SUMMARY OF "ROCKWOOD" ORE-BEARING LOCALITIES.

Although this paper is, in its entirety, little more than a summary, it has been thought best briefly to call attention once more to the areas carrying the most promising beds of iron ore. Considerable space is devoted to the description of relatively unimportant deposits of ore in the Tellico sandstone and the Grainger shale, because these dedeposits have not been described before by the Survey, but such descriptions should not obscure the fact that the bedded "Rockwood" iron ore is to be regarded as the mainstay of the southern iron industry.

By reference to the map (Pl. V) the situation in east Tennessee may be quickly grasped. The areas of outcrop of "Rockwood" ore beds more than 2 feet thick are distributed along the eastern edge of the coal field and are widely separated by areas in which the ore is less than 2 feet thick and can be worked profitably only by stripping. There are a few outcrops of ore east of Tennessee and Clinch Rivers. These are known as valley areas and contain beds that are of diverse thickness. In northeast Tennessee the workable ore occurs near La Follette and southwest of Cumberland Gap, and possibly the bed near Elk Valley may prove of value. The available ore in northeast Tennessee may be considered as tributary to blast furnaces at La Follette, Tenn., and Middlesboro, Ky. In central east Tennessee there are no very long outcrops of workable ore, but the ore beds are thicker here than elsewhere and support iron-manufacturing establishments at Rockwood and Dayton. In southeast Tennessee the greater part of the ore outcrop falls below 2 feet in thickness, but such beds as reach this thickness are near Chattanooga. There is no mining activity in Tennessee near Chattanooga at present. The ore beds that have been locally developed are not of attractive thickness and have been pretty thoroughly mined by stripping on the outcrop. Southward from Chattanooga, however (see Pl. VI), as these beds are traced into Alabama and Georgia, along opposite sides of Lookout Mountain, their thickness is found to increase, and there is considerable hard ore near Trenton, Ga., in Lookout Valley and Pudding Ridge, also under Pigeon Mountain near Estelle, that can be brought to Chattanooga furnaces at a low cost both for mining and transportation. In fact, the transportation problem is simpler for ores south of Chattanooga than it is for ores north of the city in the State of Tennessee. Southwest of Trenton and Estelle there are bodies of ore that have been mined and shipped to Chattanooga. On the west side of Lookout Mountain they extend as far as Attalla, Ala., and on the east side they extend to Gadsden, Ala., and comprise not only the area outcropping at the base of the mountain, but such valley outcrops as those of the Dirtseller and Taylor Ridge areas.

It is evident, then, that the greater part of the red ore to supply the iron industry at Chattanooga will logically come from neighboring areas in northwest Georgia and northeast Alabama, although blast furnaces in these areas will also continue to draw on local supplies of ore. The coke furnaces at Battelle, Ala., and Rising Fawn, Ga., and the charcoal furnaces at Attalla, Ala., and Cedartown and Rome, Ga., are idle at present, but the coke furnace at Alabama City, Ala., is active and is providing material for the manufacture of steel products at Alabama City. The coke furnace at Gadsden has been temporarily shut down pending reorganization of the operating company.

While this paper has not treated of the brown iron ore that forms so important a part of the furnace burdens in the South, it is well known that such deposits are becoming depleted faster than new supplies are being discovered. It is only a question of time, therefore, when this useful type of ore will have practically disappeared from the market, although, of course, that time is relatively remote. As brown ore becomes more difficult to obtain, the red ore of the Taylor Ridge and Dirtseller types containing high percentages of iron with lower lime and higher silica than ores farther west will come more into demand for mixing with the leaner and more limy red ore of the Trenton-Pudding Ridge type. The soft red ore of the Sweetwater type may also prove a source of considerable supply, and the semi-hard to hard ore of the Estelle type should prove of great value.

IRON ORE IN GRAINGER SHALE.

LOCATION.

At the request of the State geologist of Tennessee, a brief investigation of reported deposits of iron ore in the foothills of Chilhowee Mountain, southeast of Maryville, Blount County, was made by the writer in October, 1911. These deposits lie 6 to 7 miles in an air line southeast of Maryville, along "Little Mountain" or the foothills of Chilhowee Mountain, and 2 to 3 miles southwest of Little River.

TOPOGRAPHIC AND GEOLOGIC RELATIONS.

In the Knoxville geologic folio the area containing these beds is mapped as underlain by a syncline of Grainger shale, a formation of Devonian and Carboniferous age. The formation here consists mainly of shale and sandstone dipping southeast at low angles into the hills. Several branches flowing northwestward down the slope have cut narrow gulches through the formation at right angles to the strike of the beds and thus afforded sections across some rather ferruginous rocks. The Knoxville folio map shows, at a point 1¼ miles southwest of the locality visited, lying along the axis of the syncline, the northeast end of a narrow strip of Newman limestone, which is described as bluish shaly and massive limestone, of Mississippian age. The fossils collected from the ferruginous beds in the Grainger shale have been determined by E. O. Ulrich to be Mississippian.

PROSPECTS.

About 6.4 miles in an air line southeast of Maryville a large prospect pit was noted in which the following section was measured.

This pit is cut in the steep slope of a gap in Little Mountain through which a small creek descends, and is about 50 feet above the creek.

Section of ferruginous beds 6.4 miles southeast of Maryville, Tenn.

	Ft.	in.
Shale and ferruginous sandstone showing concentric weathering.		
Shale, sandy, ferruginous	1	3
Ore, soft, sandy, and argillaceous	2	1
Ore, soft and shaly		6
Ore, tough and argillaceous		4
Ore, soft and shaly		5
Ore, soft and weathered, very fossiliferous	2	2
Shale		5
Ore, tough, dark red		9
Shale		2
Ore, soft with rich streaks and shaly streaks	2	1
Shale		1
Ore, soft and fossiliferous		4
Shale, ferruginous.		

Dip, 40° S. 55° E.

Total ore, mostly lean, 8 feet 8 inches.

The material termed "ore" throughout the exposure has been thoroughly leached. It is generally soft and rather decomposed and shows limonite specks. The softest parts are brownish and do not give a very red streak. A carload of this ore is reported to have been shipped in 1907 to the blast furnace of the Embreeville Iron Co. and to have averaged 40 per cent of metallic iron. This bed is known locally as the "big seam." Analyses of this ore are given on page 320.

To judge from the content of fossil remains in the soft ore that have been leached of their lime, the hard ore probably contained considerable calcium carbonate and therefore much less iron than the soft ore. It was reported that this ferruginous bed has been tested on the outcrop by 75 pits between Little River and Tennessee River and has been found of about the quality indicated above. There is no information at hand concerning the extent of the soft ore in the direction of the dip, therefore it is not known whether the bed can be worked for soft ore or not. More light would be thrown on this question by a few drill holes, prospect slopes, and tunnels.

Between 300 and 400 yards southeast of the prospect just described, near the same creek, a prospect has been cut in another ferruginous series of beds. The stratigraphic relations indicate that these beds are higher in the formation than the "big seam," but they may represent the same beds, which have been brought to the surface again by synclinal fold, the southeast limb of which has been overturned so that the dips are toward the southeast. At both the prospects the beds dip in nearly the same direction.

At this prospect the following section was measured:

Section of ferruginous beds 6.6 miles southeast of Maryville, Tenn.

	Ft.	in.
Shale, sandy, brittle.		
Ore, alternating with streaks of shale one-half to 2 inches thick	1	1
Ore, with three shale partings one-half to 1 inch thick	2	2
Base concealed.		
Dip 52° S. 55° E.		
Total ore, about 2 feet 7 inches.		

The ore here is dark red, soft, and very similar to that in the "big seam" except that it may be slightly richer in iron.

One mile northeast from and about on the strike of the beds exposed at the pit first described a prospect was noted in beds of hard ore. The following section was measured:

Section of ferruginous beds 2 miles southwest of Little River, Tenn.

	Ft.	in.
Ore, compact, firm, dark red, fossiliferous; contains little lime	4	9
Ore, similar to above but parted by several thin streaks of shale	1	3
Ore, dark, hard, fossiliferous, calcareous	1	
Dip, 32° S. 55° E.		
Total ore, about 6 feet 9 inches.		

The material is jointed and when struck with a hammer tends to break into small blocks with nearly rectangular faces. This prospect is reported to have been made in 1908, but there was very little débris in it on account of the opening being situated on a steep hillside some 25 feet above the creek. Where this bed passes below creek level another pit had been cut, but this was full of débris at the time of visit.

ANALYSES.

The following chemical analyses of this ore from the Grainger shale (except the one made by the United States Geological Survey) were kindly furnished by Mr. J. F. Britain, of Maryville:

Analyses of iron ore in Grainger shale near Maryville, Tenn.

Locality.	Authority.[a]	Fe.	SiO_2.	Al_2O_3.	CaO.	MgO.	Mn.	P.	S.
Seam No. 1, bottom (soft ore)	T.	36.14	26.50	9.81	......	......	......	0.15	......
Seam No. 1, middle (soft ore)	T.	40.21	18.40	8.72	......	......	......	.14	......
Seam No. 1, top (soft ore)	T.	34.90	22.00	10.13	......	......	......	.16	......
Seam No. 2 (soft ore)	T.	40.41	18.40	8.95	......	......	......	.14	......
Do	T.	35.02	24.20	10.21	......	......	......	.19	......
Do	T.	10.68	61.00	13.14	......	......	......	.06	......
Hard ore	U. S.	33.47	25.58	......	11.12	......	......	.09	0.07
Do	O.	35.00	13.70	6.95	12.03	1.40	0.30	.24	......

[a] Authorities: T., Tennessee Coal & Iron Railroad Co., Ensley, Ala., 1907: O. owners of property; U. S., U. S. Geological Survey.

MINING DEVELOPMENT.

STAGES OF DEVELOPMENT.

In the southern Appalachians the mining of bedded iron ore has passed through two principal stages of development. The first stage consists in mining the ore on the outcrop and the second in mining it from underground drifts and slopes. Open-cut mining has been carried on along the outcrop practically wherever the ore has been found thick enough to be dug and shipped to market without entailing financial loss. Only in areas remote from the railways or where the ore is very thin are there no traces of former stripping operations. Stripping of the ore beds was done by hand and by scrapers drawn by horses or mules, and was carried to as great depth as was found to be profitable, depending on the thickness and quality of the ore bed, its dip, and the character of the overlying rock. A maximum thickness of 30 feet of stripping was observed at one place. The overlying shale is locally so hard that it is necessary to blast it out, after which the loosened material is shoveled into wagons and hauled to a convenient dumping place. Few of the old strip pits now show their former maximum depth, as they are partly filled by slumping of the wall, and in many places the shale has been "back filled" where the ore was removed. This phase of the iron-mining industry is now nearly obsolete, because of the exhaustion in most areas of the reserves of soft ore near the surface, although near Chamberlain, Tenn., ore is still being mined on a large scale from open cuts. Some of the old trenches and embankments that are encountered in the woods while following the outcrop of the ore beds are of considerable age, as is indicated by the size of the forest trees that have grown over them since mining was abandoned.

Underground mining has succeeded surface mining generally where the ore beds are of attractive quality and of more than the average thickness, or else where they are so situated that the cost of transportation to blast furnaces is relatively low. This does not necessarily imply that the ore is now being mined underground at all the localities at which it is available, for there are several well-located areas in Tennessee, Alabama, and Georgia underlain by good "Rockwood" ore that are not yet under development.

A further stage to which the mining of bedded iron ore may eventually progress is that of shaft mining. This would possibly be the most practicable method of working the ore below the Cumberland and Lookout plateaus if it is ever mined there. In the area between La Follette and Elk Valley and also northwest of the Rockwood-Cardiff strip the "Rockwood" ore is probably of workable thickness, although very deep below the surface. No shaft mining of "Rockwood" ore has yet been attempted in the South, but it is reported that a 50° slope is being sunk to an ore bed 1,900 feet below the surface near Oxmoor, Ala., and the results of this work will be watched with close attention by everyone interested in the development of southern iron-ore fields.

CONDITIONS AFFECTING UNDERGROUND MINING.

A summary of the most important points to be considered in relation to underground mining of bedded iron ore in the South would include (*a*) thickness of beds; (*b*) quality of ore; (*c*) attitude and structure of beds; (*d*) relation to topography and water level; (*e*) continuation of ore in depth; (*f*) distance from transportation routes; (*g*) relation to markets. The question of markets in the area under consideration is not at present serious, for most of the blast furnaces at Chattanooga, Dayton, Rockwood, and La Follette, Tenn., Gadsen and Attalla, Ala., and Rome, Ga., are, when in blast, willing to buy ore at market prices.

With regard to the minimum workable thickness, the poorest acceptable quality, and the other limitations that may be imposed by the various factors mentioned above, it may be said that all are more or less interdependent. For instance, a very rich ore can be worked in thinner and more disturbed beds than a lean ore. A rich and thick ore bed whose extent is known to be limited by a fault may not warrant the outlay necessary for a railway spur and the necessary mining equipment, which might be warranted by a thinner and leaner bed whose extent has been proved by prospecting to be much greater. The ore beds near Ooltewah are worked in a small way for paint material, but the writer has observed in the southern region no extensive underground mining of beds, whose thickness averaged less than 2 feet, nor does self-fluxing ore carrying less than an average of 25 per cent of metallic iron seem to be considered minable. In fact, no one acquainted with iron making in the South would at present be likely to become enthusiastic over mining a 2-foot bed of ore averaging 25 per cent of metallic iron, no matter how extensive or easily accessible it might be. With changing conditions, however, such an ore bed may become of considerable value at some future time, and for this reason it was thought best to include mention of the outcrop of such beds in the present report.

The maximum distance down the dip measured from the outcrop or the maximum vertical depth below the level of the outcrop to which an ore bed may profitably be worked are greatly affected by other factors. In some slopes where the ore is thin or of poor quality the limit of workability under present conditions has already been reached and mining has been discontinued. Probably when the prices of ore have risen sufficiently some of these slopes may be reopened. Other slopes that are driven in fairly thick ore of good quality have penetrated to far greater distances than the abandoned slopes and are still being operated at a profit. Obviously no workable limit can be applied to ore in such localities. For the purpose of making hasty approximations as to the tonnage of iron ore available in various parts of the United States[1] in 1908, a vertical depth of 1,000 feet was taken as an arbitrary limit to which the bedded iron ore in east Tennessee might be considered available under conditions prevailing at that time. No active slope had been reached more than half that vertical depth and some had been abandoned at much less depths. Although less than five years have elapsed since these estimates were made, one would now hesitate to place a limit of workable ore at 1,500 feet, or even at 2,000 feet, vertically below the surface. It is therefore evident that the limit of workable ore in depth is a rapidly progressing factor, and one which can not be assumed with any degree of certainty in making estimates of ore reserves.

The question has often been asked how far surface conditions could be depended on to indicate the thickness, quality, continuity, and structure of the ore bed beneath the surface. Surface indications in regard to the quality of an ore bed, provided it has been prospected back to the hard ore, are generally reliable. If prospect pits extending a sufficient distance along the outcrop have disclosed hard ore of uniformly good quality it may reasonably be assumed that the bed will continue below the surface with but little deterioration. A few exceptions to this rule have, however, been noted. The variations in quality and thickness along the outcrop should be carefully noted. Variations are characteristically more abrupt in the direction of the dip than along the strike of the ore beds. The structure of the beds overlying the ore should be noted carefully, as there naturally exists a certain parallelism in structure between surface and underlying beds. Faults or dislocations in the strata should be carefully noted, and it should at once be determined whether the beds beyond the fault have moved relatively up or down. If they have moved upward, was the upthrow sufficient to bring the ore bed above the surface and thereby terminate its extent in that immediate vicinity? If the rocks beyond the fault were dropped, instead, to what depth is the ore depressed? To what depth has the ore dipped below a given point on the surface? These questions can perhaps be answered by careful geologic study, but it may require deep drilling to settle such points definitely. The writer has in mind an operation in which, had the geologic evidence been given due weight, much expense and futile search for ore might have been avoided. At the outcrop the ore

[1] Hayes, C. W., Iron ores of the United States: Bull. U. S. Geol. Survey No. 394, 1909, pp. 70–113.

dipped at a moderate angle and conditions were evidently favorable for the driving of a slope, but a few hundred feet beyond the outcrop, in the direction of the dip, an abrupt change occurred in the surface rocks. A highly fossiliferous chert adjoined an area of nonfossiliferous chert and dolomite. The fossiliferous beds were those of the Fort Payne chert, which normally lies 150 to 200 feet above the iron ore; the nonfossiliferous beds were those of the Knox dolomite, which normally lies many hundred feet below the ore. No attention was paid to these geologic conditions, but a slope was driven and elaborate preparations were made for mining. Within a few hundred feet the slope ran into broken ground and the ore was lost. Two other slopes were driven, both of which encountered the same difficulties. The evidences of a fault were plain enough, but instead of heeding them the owners drilled a hole nearly 1,000 feet deep in search of ore in the Knox dolomite. Thorough deep drilling—in the right place—is most strongly advocated. Too little drilling has thus far been done in the ore fields, probably because of the great expense, but the expense is generally well justified, by the information obtained concerning depth to ore, thickness and quality of ore, dip of the beds, etc., provided a preliminary geologic study is made so that the drill hole is judiciously located.

The great extent to which the soft-ore beds were formerly worked at the surface is one of the factors that has led to the worst misapprehension concerning southern iron ores in general. To persons who are engaged in pursuits wholly unrelated to mining, but who may be interested in mineral lands from whose surface there was produced 20 to 50 years ago a considerable tonnage of rich soft ore, it naturally appears reasonable to believe that this mining activity should at some future time be revived. It should be necessary only to recall two points in this connection. First, surface mining is the cheapest method of working the ore beds. It requires comparatively little outlay for equipment, and it can be terminated and the outfit moved away without great loss when the work becomes unprofitable. Second, the soft ore, which was obtainable at the surface, was much richer in metallic iron than the hard ore which is to be expected below the ground-water level. If these two points are borne in mind, it will readily be seen that to be workable underground an ore bed must have a thickness much greater than the 6 to 18 inch seams that were once stripped and trenched for many miles along their outcrop in the southern Appalachian area.

CONCENTRATION OF ORE.

With the gradual depletion of the highest grade of iron-ore reserves in all countries increasing attention is being paid to the possibilities of utilizing lower grades of ore. Beneficiation of iron ore in the

Lake Superior district has been accomplished by means of extensive plants for washing, concentrating, roasting, nodulizing, and briquetting ores at various places in Minnesota, Michigan, and Wisconsin.

In the South the best-known process of beneficiating iron ores has been applied to brown ore and consists of crushing the ore, washing it in a log washer, screening the washed material, and picking the oversize on a picking belt. Why some similar methods of treatment are not more generally applied to the betterment of the shaly grades of red iron ore is difficult to understand, in view of the success that has attended certain efforts in this direction in Tennessee and Alabama within the last three years. In mining a 4-foot bed of "Rockwood" ore with thin shale partings aggregating only 4 inches in thickness, over 8 per cent by volume of shale is shot down with the ore, to which must be added more or less roof shale. In many places the total percentage of shale is probably not less than 20 per cent, and it is difficult underground to separate this broken shale from the ore; consequently most of it is hauled to the surface, and if not separated at the tipple goes on to the blast furnace. At the mines of the Brown Mining Co., in the Rockwood-Cardiff area, picking tables have been given a practical trial extending over a period of three years. The results as gaged by analyses of the picked ores compared with analyses of the ores delivered prior to the installation of the picking tables are reported to have shown a marked improvement in the ores, although inspection was necessary in order to maintain the improved grade. Gains in the average percentages of metallic iron and decreases in the average percentages of silica are apparent. Similar results are reported from operations at the Crudup mine, in northeastern Alabama, where the ore contains a considerable percentage of shale in the form of irregular seams and nodules.

Interesting experiments have been made recently in a private laboratory at Wilmington, Del., in the concentration of iron ores by the Moxham and Du Pont haloid process. In this process the ore is ground to pass 100-mesh screens and is fed into troughs containing haloid solutions of high specific gravity in which the tailings float. Separation of the lighter siliceous impurities from the heavier iron oxide concentrates is thus effected. Three tests were made of siliceous Alabama ore carrying 34.32 per cent of iron and 44.80 per cent of insoluble matter, and therefore not of workable grade. On treatment this ore yielded concentrates ranging from Fe, 41.10, insoluble, 34.50, to Fe, 53.32, insoluble, 16.90. The richer the concentrates the smaller their quantity. Of the poorer concentrates the yield was 81.2 per cent and of the richer, 48.8 per cent; but the efficiency in the latter is 97.2 per cent, compared to 75.7 per cent in the former. It is reported that this process can be carried on economically; and if so, there would appear to be a great opportunity for its application in conserving large quantities of siliceous and shaly red iron ores in the Southern States.

A series of experiments in concentrating Alabama red hematite were made by W. B. Phillips[1] in 1895 to 1897. Soft red ore containing high percentages of silica in the form of fine to coarse grains and small pebbles was crushed and screened, with the result that the percentage of iron oxide was materially increased. Considerable increases in the percentage of iron oxide were also produced by crushing and screening the ore and feeding the screenings to a magnetizing machine. As to the results Phillips says:

> These tests were * * * made on carload lots of ore and extended over several months. Conditions as to fineness of material treated, speed of the machines, amperage and voltage used, and character of the raw material were such as to give a wide range of observation. The conclusions reached were that it was entirely feasible to make concentrates of 50 per cent of iron and above from ores that were worthless for the blast furnace, and the yield of such concentrates would be not less than 50 per cent by weight of the raw ore. The extraction of the available iron in the raw ore was about 85 per cent. In some important instances the yield of workable concentrates was about 60 per cent of the raw ore treated, an ore otherwise worthless.

Similar tests were also made on limy red ores with the result that they were generally improved.

Although none of these special processes have yet been put into commercial application, it is possible that they will some time be commercially successful. It is of interest to know what would be the result of treating ore containing a large proportion of shale interlaminated with the hematite, as ore of this type is common in the vicinity of Chattanooga on both sides of the State line.

POSSIBILITY OF STEEL MANUFACTURE.

The desirability of utilizing in the vicinity of Chattanooga the products of southern blast furnaces has long been realized by the foremost iron makers of the South. According to Killebrew,[2] the Roane Iron Co. possessed at Chattanooga as early as 1881 a Siemens-Martin (open-hearth) plant for making steel and was engaged in making steel and iron rails and in rerolling old rails, but no steel plants are now operating in this vicinity.

There are no longer any serious obstacles in the way of making steel from southern iron ores so far as the character of the ore is concerned, as is shown by the successful operations of steel plants at Ensley and Gadsden, Ala. The possibilities of Chattanooga as a steel-making center are now engaging the attention of owners of

[1] The results of this work are reviewed by Phillips in "Iron making in Alabama," 3d ed., 1912, pp 102-112.
[2] Killebrew, J. B., Iron and coal of Tennessee, Tennessee Comm. Agr., Statistics, and Mines, 1881, p. 92.

iron and coal lands, technical experts, and capitalists, and it is hoped that a plan may be evolved whereby the city's great advantages for manufacturing and distributing may be grasped and still further developed by the establishment of steel mills.

Certain comprehensive reports by mining engineers and metallurgists on an assemblage of iron ore, coal, and timber properties situated within a short radius of Chattanooga in Tennessee, Georgia, and Alabama have been placed at the disposal of the writer. According to these reports it is considered feasible to utilize the raw materials at Chattanooga and to carry the manufacturing process to the last stages of the finished iron and steel products. These reports can not be reproduced here, nor can the details on which their conclusions are reached be quoted, but a few of the essential features considered in fixing on Chattanooga as the logical location for a steel plant and emphasized in a comprehensive paper already published[1] on the subject may be properly mentioned:

1. Ore resources. It is considered that sufficient ore is available in the district to warrant the establishment of a steel plant. In arriving at this conclusion the large quantities of available ore that is low in iron and silica and high in lime have been included, as well as smaller supplies of high-grade siliceous red and brown ore. The greater part of the available red ore should be mined at a reasonable cost per unit of iron.

2. Coal resources. The supplies of coking coal are considered adequate, although, owing to the irregularities of the local coal beds in both thickness and quality, the coal fields of eastern Kentucky and southwestern Virginia are also figured into the general estimates.

3. Cost of producing pig iron. This is the critical factor in steel manufacture. The cost of making pig iron under the most favorable conditions would probably be somewhat higher here than in the Birmingham district, where it is made most cheaply in the South, but it is considered that the cost should not exceed that at Birmingham by more than $1.20 a ton. The average cost at Birmingham is taken at $9.68 a ton and the estimates for Chattanooga range from $10.40 to $10.85. These estimates, it should be noted, are conditioned on large output, regular operation, and good management. The higher cost at Chattanooga is due in large part to the difference in cost of coke at the furnaces in Chattanooga and at Birmingham, and in lesser part to the difference in the cost of ores. The figures quoted are those for the early part of 1910. It is possible that the prices of coke and iron ore may have increased during the last three years. The cost of converting iron into steel should be no greater at Chat-

[1] Porter, J. J., The steel-making resources of Chattanooga: Manufacturers' Record, Baltimore, Md., May 12, 1910, pp. 49-54.

tanooga than elsewhere, and perhaps less, for steam coal is cheap and labor conditions are, as a rule, excellent.

4. Manufacturing sites. There are many favorable manufacturing sites at Chattanooga, and Tennessee River furnishes an unlimited supply of good water. Indeed, the prestige that this city has already attained is due in no small degree to the abundance of cheap factory sites and the large amount of pleasantly located land available for workmen's homes.

5. Markets. Chattanooga is, properly speaking, the most centrally located city in the South and enjoys a large and rapidly increasing local demand for structural steel and steel for general manufacturing purposes, as well as a large and expanding trade territory that will doubtless be greatly increased by the opening of the Panama Canal.

6. Competition. It is considered that in the manufacture of roofing and other light sheets, structural shapes, and light rails Chattanooga would have relatively little competition from other steel plants in the South, including those on Ohio River in Kentucky.

7. Transportation facilities. Chattanooga is especially favored in the matter of railways, no less than five systems radiating from the city. Tennessee River is navigable for eight months in the year from Chattanooga to Ohio River, and on the completion of the dam and lock at Hales Bar, below Chattanooga, there will be a sufficient stage of water to make navigation upstream more practicable than it is at present and to afford water transportation for coal from mines below the city.

TITANIFEROUS MAGNETITE BEDS ON THE BLACKFEET INDIAN RESERVATION, MONTANA.

By Eugene Stebinger.

INTRODUCTION.

A number of magnetite beds of sedimentary origin, carrying a notable percentage of iron, were found by the writer while engaged in making a geologic examination of the Blackfeet Indian Reservation in northwest Montana during the field seasons of 1911 and 1912. The beds occur in a prominent sandstone formation which can be traced for many miles, entirely across the reservation. Although the beds are of considerable economic interest, especially because of the opening of the reservation to settlement in the near future, as provided by Congress, there are apparently no published descriptions or even mention of them extant. They have not been prospected because of regulations restricting such operations on the reservation.

The magnetite beds are widely distributed over the west half of the reservation, the principal ones being found on the South Fork of Milk River in T. 37 N., R. 9 W. They are readily accessible by wagon travel from points on the Great Northern Railway, whose main line crosses the middle part of the area in a general east-west direction. The principal towns in the region are Cut Bank, a small agricultural center and railroad point situated on the east edge of the area, and Browning, at present the Indian agency for the reservation. (See Pl. VII.)

The Blackfeet Indian Reservation lies on the west border of the Great Plains region, adjacent to the east front of the Rocky Mountains. It is mainly a grassy, treeless, partly dissected plains district. The plains slope gently upward to the west, to the base of the mountains, which rise abruptly without a marked foothill development. The average elevation of the plains districts varies from 3,800 feet on the east edge of the reservation to about 5,000 feet near the base of the mountains. The mountains rise from 4,000 to 5,000 feet above the general level of the plains.

GEOLOGY OF THE MAGNETITE-BEARING ROCKS.

STRATIGRAPHY.

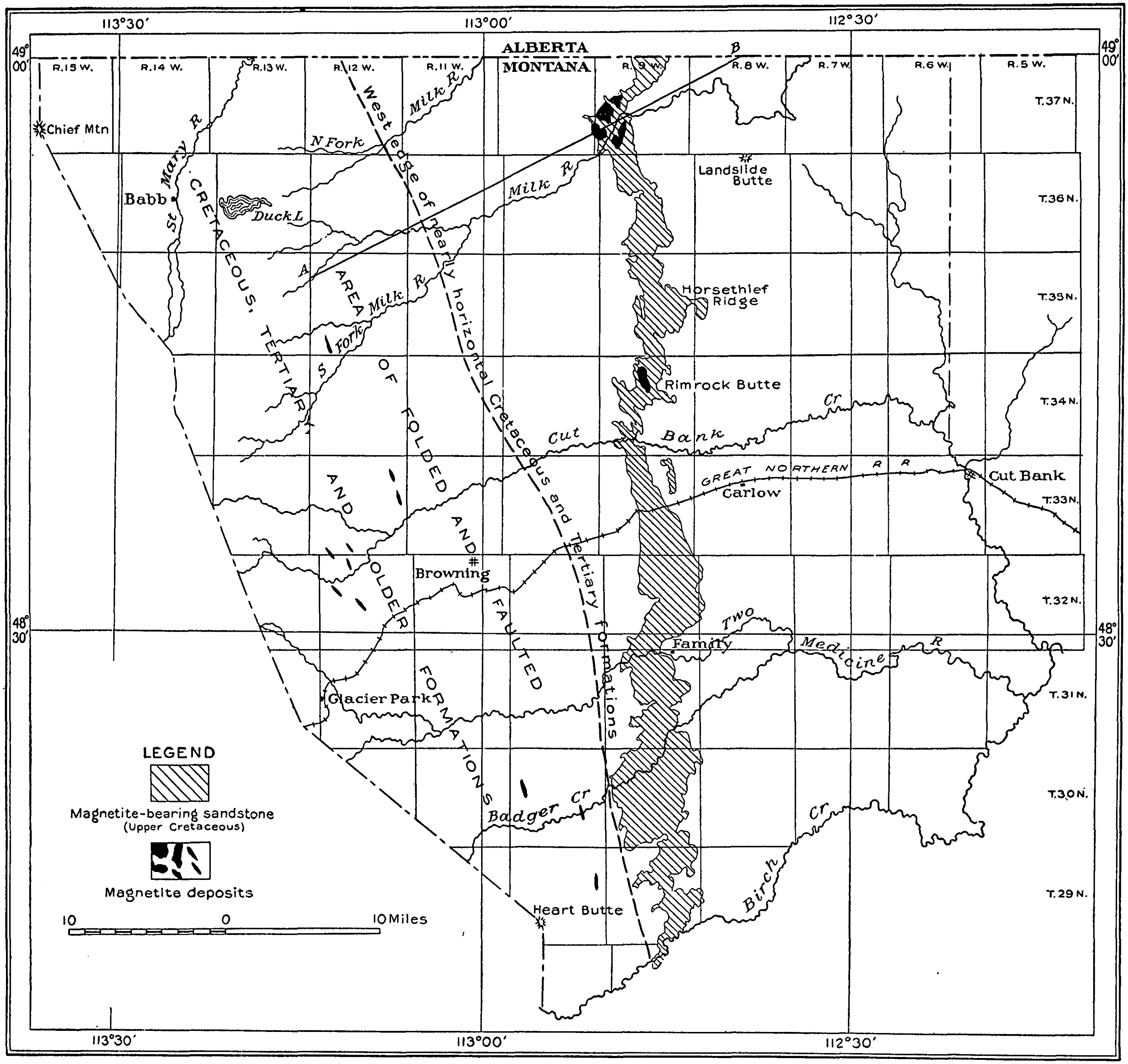
The magnetite beds on the Blackfeet Indian Reservation are found in rocks of Cretaceous age. They are confined with notable persistence to a certain sandstone formation here designated the magnetite-bearing sandstone. A knowledge of the appearance and characteristics of this formation and of the formations immediately associated with it is indispensable in tracing the magnetite beds. The relations of this sandstone to the formations above and below it are shown in the following table:

Upper Cretaceous or Eocene:
- Willow Creek formation.
- St. Mary River formation.

Upper Cretaceous:
- Magnetite-bearing sandstone.
- Bearpaw shale.

The magnetite-bearing sandstone is made up for the most part of a coarse-grained gray sandstone, composed chiefly of quartz and altered feldspars. The upper one-third of the sandstone is massive, weathers in castellated forms with a light-buff tint, and where nearly horizontal almost everywhere forms an escarpment along the outcrop. The zone in which the magnetite beds occur lies at the top of this massive member. In most places where there are no magnetite beds on this zone it is marked by several beds of greenish-gray ferruginous sandstone, usually weathering to a dark reddish brown. This ferruginous band, which is an excellent horizon marker, is typically developed on Horsethief Ridge in T. 35 N., R. 9 W., and on the escarpment lying in the township adjacent to the north. The lower member of the magnetite-bearing formation is mainly a thin-bedded slabby sandstone that tends to become shaly in the lower part, although in a few places the massive characteristics of the upper member continue to the very base of the formation, making an abrupt transition to the soft beds of the underlying Bearpaw shale.

A large number of collections of fossil invertebrates were obtained from this sandstone, principally in the upper part of the formation. Oysters and other brackish-water forms are the most common, although marine species were found in a few places, showing that the sandstone was deposited along the shallow-water margins of a marine sea or in estuaries connected with such a sea. As is usual with a sandstone formation of this nature, the thickness varies considerably. The maximum thickness measured was at the escarpment on the north side of Two Medicine River in T. 31 N., R. 9 W., where a total thickness of 360 feet was found. Thirty miles to the north, on



SKETCH MAP SHOWING MAGNETITE DEPOSITS ON THE BLACKFEET INDIAN RESERVATION, MONTANA.

Milk River, in T. 37 N., R. 9 W., where the largest magnetite deposits are found, the formation was found to be only 235 feet thick.

As shown on the map (Pl. VII), the main outcrop of the magnetite-bearing sandstone on the Blackfeet Indian Reservation lies within the undisturbed area of nearly flat-lying rocks and extends almost due north and south across the area from T. 28 N., R. 9 W., to T. 37 N., R. 9 W., a total distance of nearly 60 miles. There is no marked variation in the character of the formation along this extensive outcrop, except the change in thickness mentioned above. The best exposures on this belt of outcrop are on a series of prominent eastward-facing escarpments present at intervals along its entire length. The most prominent exposures in the northern part of the area are on Horsethief Ridge and Rimrock Butte, both of which lie between Cut Bank Creek and Milk River. In the southern part of the reservation the sandstone forms bold cliffs and extensive escarpments where it outcrops on Two Medicine River, Badger Creek, and the buttes in T. 29 N., R. 9 W., south of Four Horns Lake.

In the area of folded and faulted rocks in the western part of the reservation, immediately adjoining the mountains, the magnetite-bearing sandstone has a topographic development very different from that described above. The formation is here exposed in numerous hogback ridges, which, lying parallel to one another and in places repeated by faulting, have a uniform northwest-southeast trend in accordance with the general strike of the rock structure of the region. The outcrops of the formation in this disturbed belt are not extensive enough to be shown on a small scale and no attempt has been made to outline them on Plate VII. An excellent example of this hogback topography, developed by the magnetite-bearing sandstone, is on the Middle Fork of Milk River in Tps. 35 and 36 N., R. 12 W., near the Douglas ranch. Here a bold westward-dipping strike ridge of the sandstone extends for 3 miles across the valley and is the most prominent topographic feature in that vicinity. Similar bold strike ridges are present in the valley of Milk River north of the Paisley mine, in T. 37 N., R. 13 W.; in the valley of the South Fork of Milk River; in the vicinity of Horse Lake; and on Two Medicine River near the mouth of Little Badger Creek, in T. 31 N., R. 10 W.

The magnetite-bearing sandstone is very similar in appearance to the Eagle sandstone, which occurs about 2,500 feet below it stratigraphically. Each of these formations has about the same thickness, each has a massive sandstone member in the upper part resting upon a thin-bedded shaly member, and the two are almost identical, even in minor lithologic details. In a disturbed area where these formations are brought into close relations by folding and faulting. the lithologic similarity makes it very difficult to tell them apart. This difficulty is further increased by the fact that many of the brackish-water fossils which occur at the top of the magnetite-bearing sandstone are known to range downward to about the top of the Eagle sandstone, making purely paleontologic determinations of these horizons more or less uncertain.

The Bearpaw shale, lying conformably beneath the magnetite-bearing sandstone, consists almost entirely of a dark clay shale carrying an abundance of fossil shells of genera known to exist only in purely marine waters. The formation was first studied in the vicinity of the Bearpaw Mountains, in Chouteau County, Mont. The corresponding shales, as found on the Blackfeet Indian Reservation, are almost identical in lithologic appearance, stratigraphic position, and fossil content with those of the type locality. In the upper 100 feet the formation gradually becomes more sandy toward the base of the magnetite-bearing sandstone, and except where the massive member of the magnetite-bearing sandstone is developed to the very base of that formation, the line of contact between the two is not clearly defined. The lower part of the Bearpaw shale is a homogeneous mass of dark-gray clay shale, characterized by the occurrence of limestone concretions that are irregularly distributed at various horizons and carry practically all the fossils found in the formation.

Excellent exposures of the Bearpaw shale are found on cut banks of Two Medicine River from 1 to 3 miles below Family and on the buttes lying to the northeast of these exposures. Other localities are on Cut Bank Creek in T. 34 N., Rs. 8 and 9 W., where dark-gray clay shales are exposed for 5 miles along the south side of the creek, and on Landslide Butte, where the formation is well exposed both in the steep slopes made by the landslide on the west side of the butte and in the draw running northwestward from it. The thickness of the Bearpaw shale, as measured at the outcrops on Two Medicine River below Family is 490 feet.

The St. Mary River formation overlies the magnetite-bearing sandstone conformably and is in immediate contact with the magnetite beds at the top of that sandstone. The name St. Mary River was given to these rocks by the geologists of the Canadian Geological Survey, who first studied the formation on the banks of St. Mary River, in Alberta, a few miles north of the reservation boundary. The formation consists essentially of an irregularly bedded mass of light-gray fresh and brackish water clays and sandstones. The clays predominate, making up over two-thirds of the bulk of the formation; the sandstones are in places only partly indurated and are not persistent, commonly thinning out and merging into clays within a short distance. Although the greater part of the formation is gray to light greenish-gray in color, red and variegated banded clays occur in the upper part. The thickness of the St. Mary River formation as measured along Little Rocky Coulee in T. 35 N., R. 9 W., and T. 36 N., R. 10 W., is 990 feet.

STRUCTURE.

Structurally the Blackfeet Indian Reservation can be divided into two large units differing greatly in the amount of deformation to which the rocks have been subjected.

In the area west of a slightly curving line shown on the map (Pl. VII) as extending from a point on Birch Creek in T. 28 N., R. 9 W., to a point on the Canadian boundary in T. 37 N., R. 12 W., the rocks have been intensely folded and faulted by thrust stresses acting from the southwest. (See fig. 31.) In many places the individual formations are so much crushed and broken that it is impossible to identify them with certainty. The one constant feature in this whole disturbed area is the uniform northwest-southeast strike of the rocks. Because of this parallelism in the strike of the steeply dipping rocks and because of the lenticular shape of the magnetite-bearing beds, the outcrops of the deposits in this part of the reservation appear on the map as small flaxseed-shaped areas all oriented in the same general direction.

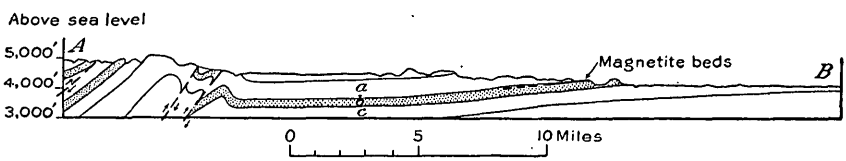


FIGURE 31.—Section along line *A–B*, Plate VII, showing relations of magnetite-bearing sandstone in Blackfeet Indian Reservation, Mont. *a*, St. Mary River formation; *b*, magnetite-bearing sandstone; *c*, Bearpaw shale.

The structure of the part of the reservation lying east of the line above mentioned is very simple, the rocks being only slightly disturbed and lying very nearly horizontal. The dip is very generally westward and varies from practically zero to 5° in gentle undulating flexures, with an average of not over 2°. This area of nearly flat-lying rocks forms part of the west limb of a very broad anticline or arch in the rock strata, whose axis, trending in a north-south direction, lies east of the Blackfeet Indian Reservation in the vicinity of Sweet Grass Hills. The change in structure from the nearly horizontal rocks in the east half of the reservation to the steeply dipping disturbed rocks in the west half is very abrupt. Where exposures are good, especially along the major stream valleys, this change can be seen to occur within a few feet, without an intermediate zone of gentle folding.

OCCURRENCE AND CHARACTER OF THE MAGNETITE BEDS.

The magnetite beds on the Blackfeet Indian Reservation are confined very persistently to a zone occupying the upper 25 feet of the sandstone formation in which they are found. Although this zone does not invariably contain beds that are rich in magnetite, it is nearly everywhere distinguished by sandstones that are much more ferruginous than the underlying rocks and that therefore weather with a dark iron stain, making them very conspicuous. Where deposits rich in magnetite occur, the zone usually consists of two to four beds of high-grade rock intercalated with leaner sandstones, as is shown in figure 32, which illustrates a typical section of the deposits. In some places, however, only one bed occurs, varying from only a few inches to as much as 6 feet in thickness and associated with more or less lean sandstone having a very low iron content. The beds rich in magnetite are more indurated and therefore resist weathering better than the lean sandstones, standing out in small steplike ledges. The entire deposit acquires on weathering a deep reddish brown or rusty color which presents a marked contrast to the light buff to gray of the underlying sandstone.

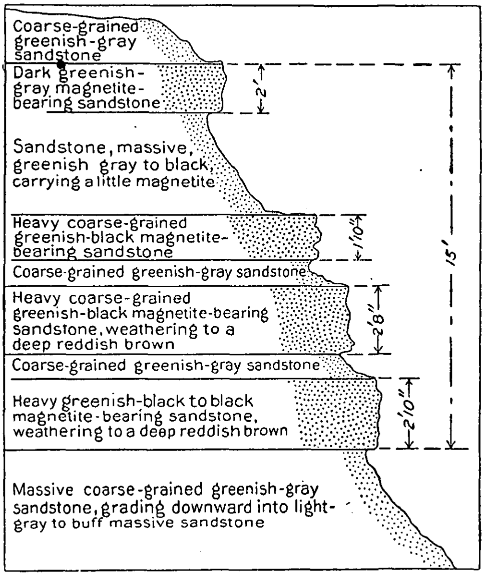


FIGURE 32.—Section of magnetite-bearing sandstones at the mouth of Kennedy Coulee, on Milk River, in the NE. ¼ sec. 30, T. 37 N., R. 9 W., Montana.

The rock in the iron deposits here described, when examined with the naked eye on a fresh face, is seen to be a dense fine-grained aggregate composed mainly of magnetite. By turning the hand specimen in the light, the minute metallic faces of the individual magnetite grains can be plainly seen, but other minerals can not be distinguished except in rock of very low grade, in which minute specks of feldspar and quartz are visible. In places the ore presents a finely banded appearance due to the alternation of small blackish layers of almost pure magnetite with light-gray layers composed chiefly of quartz and feldspar. The banding is in many places perfectly developed, individual layers being rarely over one-fourth of an inch thick and ranging from that thickness down to a knife-edge. The color of the iron rock varies from a dull black in material carrying from 40 to 50 per cent of iron to a deep greenish black in material carrying from 25 to 30 per cent. The specific gravity also varies with the iron content, averaging about 4.5 in the higher-grade rock and much less in the leaner material. The low-grade parts of the deposits could be readily separated from the richer material by hand sorting, because of their lower specific gravity and lighter color.

As seen under the microscope, the magnetite-bearing sandstone is a typical clastic aggregate with magnetite, quartz, and altered feldspars as the dominant minerals and zircon, garnet, titanite, and ilmenite as accessory minerals. Silica and an unidentified chloritic mineral are the principal cementing substances. The rock is undoubtedly of sedimentary origin and is very probably an indurated "black sand" such as occurs in many places along present sea beaches, especially along the Pacific coast. Day and Richards,[1] in a study of black sands which included most of the well-known beach sands of the Oregon and California coasts, found that ilmenite, garnet, and zircon, in the order named, were the most abundant accessory minerals commonly found.

Analyses of four samples of magnetite-bearing sandstone from widely scattered localities on the Blackfeet Indian Reservation show an iron content ranging from 27.3 to 49.3 per cent. The samples for analyses 2721 a, b, and c, given below, were all obtained by cutting a channel across the face of the outcrop of the deposits and then mixing and quartering the material thus obtained so as to give as true an average as possible. Sample 2658 was a hand specimen of average material. The amount of titanium oxide present in the samples varies from 6.8 to 12.8 per cent and is probably contained not only in the titanium-bearing minerals, ilmenite and titanite, but also in the magnetite.

At present iron ores containing more than 1 per cent of titanium oxide are considered to be of no commercial value, regardless of the amount of iron present, because the material can not be smelted successfully. The iron that can be smelted from such ores is of good quality, but the titanium-bearing slags are too viscous and sticky to allow successful furnace operations. However, metallurgists[2] are not hopeless as to the possibilities of eventually being able to smelt titaniferous iron ores, and it is not improbable that they will finally be used in making titanium tool steel.

Partial analyses of samples from the magnetite deposits of Blackfeet Indian Reservation, Mont.

[F. W. Clarke, chemist in charge.]

	2721a.	2721b.	2721c.	2658.
Location	NE. ¼ sec. 30, T. 37 N., R. 9 W.	SW. ¼ sec. 29, T. 37 N., R. 9 W.	SE. ¼ sec. 13, T. 33 N., R. 12 W.	NE. ¼ sec. 9 T. 34 N., R. 9 W.
Total thickness of beds included in sample.	9 feet 4 inches	2 feet 4 inches	7 feet	Grab sample.
Fe	27.3	33.2	49.3	35.73
TiO_2	8.3	10.6	6.8	12.81
S	.034	.018	.080	Not det.
P_2O_5	None.	.16	.073	Not det.
SiO_2	Not det.	Not det.	Not det.	29.62

[1] Day, D. T., and Richards, R. H., Useful minerals in black sands of the Pacific slope: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 1228.

[2] See Rossi, A. J., Report on titanium ores in blast furnaces: Trans. Am. Inst. Min. Eng., vol. 21, 1893, p. 2

DETAILS OF THE DEPOSITS.

Beds on Milk River near mouth of Kennedy Coulee.—The thickest beds found on the reservation occur at the mouth of Kennedy Coulee, near the Croff ranch, in T. 37 N., R. 9 W. The iron-bearing beds are prominently exposed above low cliffs of the nearly horizontal sandstone on the north side of the coulee in the NE. ¼ sec. 30. The section of this deposit presented in figure 32 shows 9 feet 4 inches of high-grade magnetite-bearing sandstone distributed in four beds intercalated with a leaner sandstone. As shown by analysis 2721a the beds average 27.3 per cent of iron and 8.3 per cent of titanium oxide.

At the mouth of Coal Creek, in sec. 20, about 1½ miles northeast of the locality just mentioned, the zone is well exposed, showing about 12 feet of ferruginous rocks, which evidently have a lower iron content than the average of the deposits and which therefore were not sampled.

In the same township, on the opposite side of Milk River, the magnetite-bearing sandstone is well exposed in steep cliffs averaging about 100 feet in height. The cliffs are capped by iron-stained sandstones from 10 to 20 feet in total thickness. The greater part of these sandstones can not be classed as high-grade rock, although a few thin beds, in no place reaching an aggregate thickness of more than 4 feet, are rich in magnetite. A sample from this locality, taken from the exposures opposite the ranch house in the SW. ¼ sec. 29, contains 33.2 per cent of iron and 10.6 per cent of titanium oxide.

Beds on Rimrock Butte.—Rimrock Butte, located in T. 34 N., R. 9 W., between Powell and Cabelle coulees, is a flat-topped eminence with bold cliffs on its east side in which is exposed the massive member of the magnetite-bearing sandstone, here very nearly horizontal. The top of the butte is capped by a 5 to 8 foot dark ferruginous member containing a single bed of high-grade magnetite-bearing sandstone averaging 1 foot in thickness. In the N. ½ sec. 9 this rich magnetite bed is weathered out on the surface over the top of the butte, making an impressive bare-rock exposure of shiny black iron ore. A hand specimen of material taken from this exposure gave on analysis 35.73 per cent of iron and 12.81 per cent of titanium oxide.

Beds in faulted and folded areas adjacent to the mountains.—In the area of faulted and folded rocks adjacent to the mountains there are numerous widely distributed beds of the magnetite sandstones. Because of the prevailing steep dips the outcrops of the beds appear as narrow bands parallel to the strike of the magnetite-bearing sandstone. The most important of these exposures is in sec. 13, T. 33 N., R. 12 W., on a remarkably even and flat plain lying between Cut Bank and Greasewood creeks. The ore at this locality occurs on the west side of a low ridge of the magnetite-bearing sandstone, dipping 40° SW., which is a very prominent landmark because of the flatness of the surrounding country. The single bed of the iron ore present is 7 feet thick and is the richest iron-bearing material found on the reservation, the sample taken giving 49.3 per cent of iron. It is a very heavy fine to medium grained greenish-black rock, and in a few places shows a perfect banding, due to the presence of minute light-gray layers of quartz and feldspar alternating with black layers composed almost entirely of magnetite. Two miles to the northwest, on the south side of the creek, in sec. 11, on the line of strike with the sandstones just mentioned, there is another single bed of iron, 4 feet thick and dipping 30°–40° SW. The outcrop is very poorly exposed and can be traced only a few hundred feet along the strike. Because of the poor exposures it can not be stated with certainty that the iron-bearing bed is continuous between the two localities mentioned above, although this is not improbable.

CONCLUSIONS.

1. The magnetite beds of the Blackfeet Indian Reservation are of sedimentary origin and are restricted to a zone at the top of a sandstone formation of Upper Cretaceous age.

2. The beds show a close mineralogic resemblance to the accumulations of "black sands" which are found in many places along present-day beaches of the Oregon and California coasts.

3. The beds were not laid down over the entire area of the formation in which they occur, but seem to have accumulated only in a number of small, widely scattered areas which contain rich magnetite sandstones reaching a thickness of 9 feet, although the average thickness is not over 4 to 5 feet.

4. A considerable tonnage of ore which would average about 50 per cent of iron could be hand sorted from these deposits, although the average of the material available would probably not run more than 30 to 40 per cent.

5. The proportion of titanium oxide in the ores is considerable, averaging over 12 per cent in one sample. This high titanium content renders these ores unfit for use, according to present metallurgical practice, although it must be recognized that ores of this type may eventually be successfully smelted.

RECENT DISCOVERIES OF "CLINTON" IRON ORE IN EASTERN WISCONSIN.

By Fredrik T. Thwaites.[1]

A comparatively little known resource of Wisconsin is the sedimentary iron ore of the Silurian strata. This ore is correlated with and is of the same character as tne well-known Clinton ore of New York and of the Birmingham district of Alabama. Though now mined in Wisconsin only at Iron Ridge, near Mayville, Dodge County, several other deposits have been discovered in the State, some of which appear to be large.

The ore is an oolitic hematite containing various amounts of silica and calcium carbonate. The iron content in the ore as shipped averages from 40 to 47 per cent; the phosphorus runs over 1 per cent. Although of low grade compared with most of the ores now in use, the "Clinton" ore is well suited by its high calcium and phosphorus for use with the basic open-hearth process. The nearness of the Wisconsin deposits to the Great Lakes and the cities of Milwaukee and Chicago also makes for their importance in the near future if not to-day. The Iron Ridge ore is smelted both at Mayville and Milwaukee, often being used in connection with Lake Superior ore.

The "Clinton" hematite is an essentially unaltered sedimentary deposit which occurs in broad lenses in eastern Wisconsin, between the Niagara dolomite (Silurian) and the underlying Maquoketa ("Cincinnati") shale (Ordovician). The lenses vary greatly in thickness, one of 55 feet being the thickest known. On the other hand, their extent is so meager that by far the greatest portion of the beds at the ore horizon show not even a trace of the "Clinton" ore. At other places at or near this horizon beds of red rock are interstratified with the lower part of the Niagara dolomite, whose relation to the known "Clinton" ore has not been determined. The only sample of these red beds examined by the writer was a very ferruginous limestone. It is not known whether or not any of these interstratified red beds represent the "Clinton" oolitic ore.

The strata in eastern Wisconsin dip gently toward the east beneath Lake Michigan. The outcrop of the beds in which the ore occurs is from 20 to 30 miles west of the lake, as shown on the accompanying map (fig. 33). At no point in eastern Wisconsin are the beds known to be more than 900 feet below the surface.

[1] Curator of Geological Museum, University of Wisconsin.

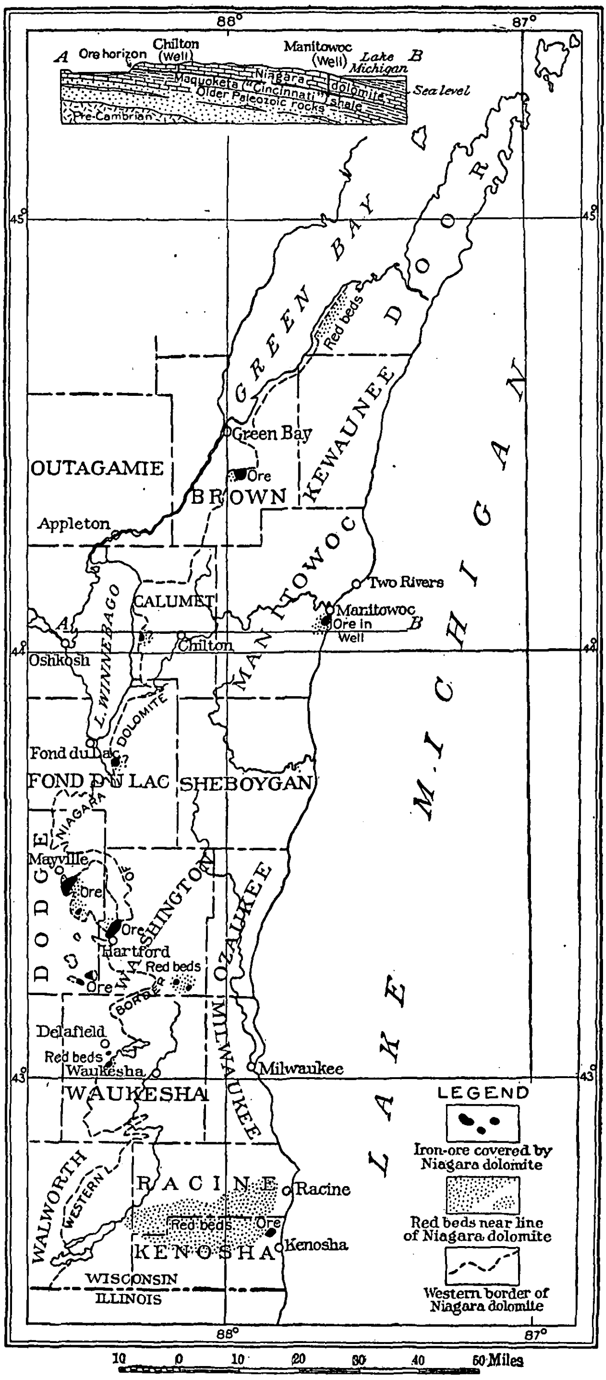


FIGURE 33.—Map and section showing location of deposits of "Clinton" iron ore in eastern Wisconsin.

The only mines now operating in the "Clinton" ore are at Iron Ridge, near Mayville, Dodge County. Here a bold bluff occurs at the west edge of the Niagara dolomite, so that the ore body was easily discovered. Mining has been carried on for a long time both by open cuts in the broken dolomite and by underground workings. The thickness of ore worked varies from 6 to nearly 30 feet. To the south and southeast of the mines erosion has removed the entire formation. Two apparently separate lenses are worked, whose longer axes have so far as known an east-northeast and west-southwest course. Recently a large amount of ore (several million tons) has been found by drilling to the east and northeast and is being developed by a shaft nearly a mile back from the outcrop.

The "Clinton" hematite outcrops also in the vicinity of Green Bay, where its maximum known thickness is less than 5 feet. The ore is of lower grade than usual, as it contains interbedded layers of shale. No recent detailed geologic studies have been made in this vicinity, and the results of well drilling are not known to the writer. West of Chilton and near Fond du Lac the ore is said to be thinner. No very serious exploration has been undertaken at any of these places, and so far as known the results of well drilling do not give any encouragement. If thick lenses of ore were ever formed in these places, erosion may have removed the better portion of the deposits. Owing to the heavy covering of drift much of the line of outcrop has never been explored.

Away from the naturally exposed deposits the search for "Clinton" ore is much more difficult. Only a small proportion of the wells go deep enough to reach the proper horizon, and of these the great majority are in Milwaukee and the adjacent cities. From the records so far collected (mainly by William C. Alden for the United States Geological Survey) it appears that few wells have encountered any recognizable "Clinton" ore.[1] The best-known locality where the "Clinton" ore occurs away from its natural exposures is at Hartford, Washington County, where the ore has been found in wells at depths ranging from 20 to more than 100 feet. It appears to extend under an area about 1 by 3 miles in extent, the longer axis running north-northeast and south-southwest, and is said not to occur east of the city. The thickness is usually only a few feet, although it has been asserted to be 20 feet or more. The ore appears to be broken up and mixed or perhaps interstratified with limestone. Ore is also reported in one well 6 miles to the northwest.

Southwest of Hartford, in Ashippun, Dodge County, several wells are reported to strike the "Clinton" ore. These are situated on two outliers of the Niagara dolomite, in secs. 21, 22, and 27, T. 9, R. 17 E. From 8 to 20 feet of "red rock," possibly ore, is reported to occur

[1] Chamberlin, T. C., Geology of Wisconsin, 1873-1879, vol. 2, pp. 328-334. Later information regarding all localities south of latitude 44° obtained from W. C. Alden, U. S. Geological Survey.

at depths of 10 to 135 feet. Some float ore is found. The well records appear to indicate an elliptical lens with its longer axis running northeast and southwest, but severed into halves by erosion. Red rock is also reported from two wells southeast of Delafield, Waukesha County, and from two in Germantown, Washington County. Red rock also occurs locally in Door County.

About 4 miles northwest of Kenosha, in the town of Somers (SW. ¼ SE. ¼ sec. 14, T. 2, R. 22 E.), Kenosha County, a well drilled with a diamond drill shows the following:

Record of well in Somers Township, Wis.

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift or "surface"	171	171
Niagara dolomite, generally firm but somewhat creviced toward the base	130	301
Reddish to purplish limestone	32	333
Iron ore (so described by driller of well)	18	351
Maquoketa ("Cincinnati") shale.		

Many wells to the south and west penetrate red beds at various depths. The approximate outline of the area where these beds are common is shown on the map.

Recently samples from a well drilled southwest of Manitowoc for the Northern Grain Co. came under the writer's observation, being presented to the museum of the University of Wisconsin by the United States Geological Survey. The character of the "Clinton" ore there penetrated had heretofore escaped observation.[1] The succession is as follows:

Record of well southwest of Manitowoc, Wis.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	90	90
Niagara dolomite; hard gray to brownish dolomite, softer at base. Water found down to 763 feet. Yield 350 gallons a minute, with casing at 400 feet	735	825
"Clinton" ore; soft dark-red calcareous oolitic hematite	30	855
Same, but oolitic texture is less marked, so is probably more clayey	25	880
Maquoketa ("Cincinnati") shale.		

An assay[2] of the samples from the "Clinton" ore gave iron 33.98 per cent and phosphorus 1.041 per cent, but this result should be received with caution on account of the method of taking the samples, which might result in concentrating the heavy minerals. Nevertheless, it is clear that at least the upper 30 feet of the deposit is ore of promising character. Nothing is known of the lateral extent of the

[1] For full record of this well, see Fuller, M. L., and Sanford, Samuel, Record of deep-well drilling for 1905: Bull. U. S. Geol. Survey No. 298, 1906, p. 295.

[2] Analysis by Lerch Brothers, Virginia, Minn.

ore, as wells of sufficient depth to reach it are not at all common in the vicinity. No ore is reported from the deep well at Two Rivers, 8 miles to the northeast.

Several of the localities described are worthy of consideration for exploration. Information by which to form any accurate judgment is at present lacking regarding most of them. The area in Ashippun, Dodge County, is of fairly promising character, but the information is not definite and erosion has seriously reduced the area of "Clinton" ore. The same may be said of the area near Green Bay. Owing to the fact that no attempt to mine the ore has ever been made at Hartford it would seem that the occurrence is not promising, although it has not been thoroughly tested. Most encouragement may be offered to exploration of the proved thick "Clinton" ore in Kenosha County, and especially of that at Manitowoc. Both of these deposits are admirably situated with regard to transportation facilities. The depth (333 and 825 feet, respectively) to the deposits beneath water-bearing strata is the only adverse circumstance. Nevertheless, as many wells find but little water in the dense Niagara dolomite, below its creviced surface, it is probable that the water could be shut off and the ore extracted without great difficulty. Under normal conditions water can not come from beds below on account of the barrier interposed by the impervious Maquoketa ("Cincinnati") shale.

It may safely be said that no insuperable obstacle is known to exist which might hinder the further development of "Clinton" iron ores in eastern Wisconsin. There are at least two localities where "Clinton" ore beds that are reported to be thick and are well situated with regard to transportation are now believed to occur. When it is considered that these beds usually extend with fair uniformity over considerable areas, and that a thickness of 10 feet means over 30,000 long tons to the acre, it may be seen that the possibilities are good for the discovery of an enormous quantity of ore. It is of the greatest practical value that samples be preserved in the drilling of deep wells and submitted to expert examination.

SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

The principal papers on iron and manganese ores published by the United States Geological Survey are listed below. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washngton, 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; the folios only from the Director. The publications marked "Exhausted" are no longer available for distribution but may be consulted at the larger libraries of the country. Several geologic folios not given in this list contain descriptions of iron-ore deposits of more or less importance.

Ball, S. H., The Hartville iron ore range, Wyoming: Bull. 315, 1907, pp. 190–205. 50c.

——— Titaniferous iron ores of Iron Mountain, Wyoming: Bull. 315, 1907, pp. 206–212. 50c.

Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

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Bayley, W. S., The Menominee iron-bearing district of Michigan: Mon. 46, 1904, 513 pp. $1.75.

Bayley, W. S., and others, Passaic folio (No. 157), Geol. Atlas U. S., 1908. Exhausted.

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——— The brown ores of the Russellville district, Alabama: Bull. 315, 1907, pp. 152–160. 50c.

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Burchard, E. F., Tonnage estimates of Clinton iron ore in the Chattanooga region of Tennessee, Georgia, and Alabama: Bull. 380, 1909, pp. 169–187. 40c.

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Burchard, E. F., Butts, Charles, and Eckel, E. C., Iron ores, fuels, and fluxes of the Birmingham district, Alabama: Bull. 400, 1910, 204 pp.

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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: Nineteenth Ann. Rept., pt. 3, 1898, pp. 1–157. $2.25. Also Mon. 36, 1899, 512 pp. $2.

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——— The iron ores of the Appalachian region in Virginia: Bull. 380, 1909, pp. 215–254. 40c.

——— Manganese deposits of the United States: Bull. 380, 1909, pp. 255–277. 40c.

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——— Iron ores near Dayton, Nev.: Bull. 430, 1910, pp. 240–246.

——— Deposits of brown iron ore near Dillsburg, York County, Pa.: Bull. 430, 1910, pp. 250–255.

——— Iron-ore deposits of the Eagle Mountains, California: Bull. 503, 1912. 81 pp.

HARDER, E. C., and RICH, J. L., The Iron Age iron-ore deposit near Dale, San Bernardino County, Cal.: Bull. 430, 1910, pp. 228–239.

HAYES, C. W., Manganese ores of the Cartersville district, Georgia: Bull. 213, 1903, p. 232. 25c.

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——— The Lake Superior mining region during 1903: Bull. 225, 1904, pp. 215–220. 35c.

——— Iron ores in southern Utah: Bull. 225, 1904, pp. 229–237. 35c.

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ALUMINUM ORES.

ALUNITE IN GRANITE PORPHYRY NEAR PATAGONIA, ARIZONA.

By Frank C. Schrader.

INTRODUCTION.

The study of certain specimens collected in 1909, during a geologic survey of the Nogales quadrangle, in southern Arizona, has revealed a new occurrence of alunite. The mineral is disseminated in an altered granite prophyry at a locality 5 miles south of the town of Patagonia, the specimens studied being obtained from the 3 R mines, which are situated in the Palmetto mining district, in Santa Cruz County, about 10 miles north of the Mexican boundary. Patagonia is on the Benson-Nogales branch of the Southern Pacific Railroad.

RELIEF.

The 3 R mines are on the upper west slope of the north end of the Patagonia Mountains, one of the north-south desert ranges of the Great Basin type, at an elevation of about 5,400 feet. The topography, as expressed on the Nogales topographic sheet of the United States Geological Survey, is ruggedly mountainous, being of the type produced by uplift, faulting, and deep erosion of granitoid rocks. From the border of the gently westward sloping valley plain of Sonoita Creek, at the northwest base of the mountains, the surface rises about 2,000 feet to the summit in a distance of 2 miles. The most feasible means of approach is by way of 3 R Gulch, on the southwest, whence the rise to the mines is about 1,000 feet in a distance of one-third of a mile.

GEOLOGY.

The country rock in this part of the mountains is a medium to coarse grained gray granite porphyry. It occupies a north-south belt about 2 miles wide by 4 miles long, near the center of which the 3 R mines are located. Quartz and orthoclase in large phenocrysts and their aggregates constitute more than two-thirds of the rock;

the remainder seems to represent a fine-grained groundmass of the same minerals. Pyrite and chalcopyrite, which seem to be primary, occur in both the orthoclase and the quartz. Apatite and zircon are present as accessories.

The rock is vertically sliced by two systems of sheeting, of which the dominant system trends about north and south, parallel with the axis of the range and the Colossus lode, and the other about N. 75° E. Mineralized shear zones on which mines are located occur in both systems and are in places marked by conspicuous ledges, such as that of the Blue Rock No. 8, southeast of the 3 R mine and belonging to the east-west system. The rock, especially in the vicinity of the north-south shear zones, has also been pressed and sheared to a high degree, the resulting structure causing it to weather like a schist, which it locally resembles. It is cut by a few dikes of rhyolite and a younger granite porphyry. The rock was probably at one time a pegmatite, but it has been dynamically and otherwise altered, principally by sericitization and kaolinization.

THE ALUNITE.

The mineral alunite is a hydrous sulphate of aluminum and potassium, having the formula $K_2O.3Al_2O_3.4SO_3.6H_2O$. When pure it contains 11.4 per cent of potassa (K_2O), 37 per cent of alumina (Al_2O_3), 38.6 per cent of sulphuric anhydride (SO_3), and 13 per cent of water (H_2O).

The alunite here described occurs in the wall rock of the Evening Star prospect, belonging to the 3 R group of copper mines, in which deposits of rich chalcocite ore have recently been discovered. Here the altered granite porphyry, instead of being sericitized and gray, is alunitized and pink. The alunite almost wholly replaces the orthoclase, so that the rock consists chiefly of quartz and alunite with a little pyrite and chalcopyrite. The zone of alunitization extends at least several feet laterally from the vein fissure, and perhaps to a great distance. It was observed only incidentally in the course of examination of the copper deposits, and its width was not determined.

The rock in its present crushed and altered state presents a sort of graphic structure. It shows a general parallel pegmatitic arrangement of the minerals, quartz, and alunite alternating with each other in elongated lenslike bodies or discontinuous bands with irregular outline. These bands vary from about 0.1 to 0.4 inch in width. They are traversed at nearly right angles by a very close lamination or schistose structure, which amounts almost to cleavage and which is most conspicuous in the quartz. In the former feldspar areas the structure has been dimmed or largely effaced by the replacing aggregates of alunite, which is in part pseudomorphic after the orthoclase.

In or paralleling this schistose structure in the alunite occur also numerous veinlets of alunite having comb structure, by which a single crystal area is commonly sliced into six or eight or even ten to twelve sections. The veinlets are bilateral, with the comb structure locally interlocking. They are composed of slender elongated crystals, which are apparently made up of numerous smaller, almost cryptocrystalline aggregate forms, or successive zonelike stages of growth. The veinlets that extend into the adjoining quartz are generally less well developed.

Owing to the recent activity in the potash industry and the recognition of alunite as a possible source of potash, the interest in this occurrence centers in its potash as well as its alumina content. The rock from the Evening Star prospect was found by chemical test to contain abundant sulphates of aluminum and potassium. According to E. S. Larsen, who examined it microscopically and is familiar with the occurrence of alunite-bearing rocks in other fields, it is estimated to contain nearly half alunite.

The description here given is based mainly on office study of a few hand specimens collected from a deposit which was observed only incidentally in the field and which is not shown to be of commercial value. It serves to call attention, however, to the presence of the alunite in the porphyry and suggests that other deposits of the mineral may occur in this formation, which in the 3 R belt alone occupies an area of about 9 square miles. This porphyry belt would commend itself for prospecting in case a practical process is developed for the reduction of alunite to soluble potash salts, and in the light of the fact that "a study of the alunite deposits near Marysvale, Utah, and in other parts of the Western States by the United States Geological Survey indicates that the mineral alunite may become at some future time an important source of alumina."[1]

The occurrence of the alunite in the granite porphyry, a post-Paleozoic hypabyssal or plutonic rock, is unusual, as most of the known deposits of alunite, especially in the western United States, are in Tertiary volcanic rocks.[2]

The alunite here described seems to have been formed chiefly by the metasomatic replacement of the orthoclase feldspar in the granite porphyry, a process accomplished by hydrothermal solutions that ascended the fissure after the intrusion of the granite porphyry itself,

[1] Phalen, W. C., The production of bauxite and aluminum in 1911: Mineral Resources U. S. for 1911, pt. 1, U. S. Geol. Survey, 1912, p. 924.

[2] Cross, Whitman, On alunite and diaspore from the Rosita Hills, Colorado: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 466–475; Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 314. Hill, R. T., Camp Alunite, a new Nevada gold district: Eng. and Min. Jour., vol. 86, 1908, pp. 1203–1206. Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: Prof. Paper U. S. Geol. Survey No. 66, 1909, pp. 129–133, 193. Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912. Larsen, E. S., Alunite in the San Cristobal quadrangle, Colorado: Bull. U. S. Geol. Survey No. 530, 1913, pp. 179–188.

or perhaps after the eruption of the later granite porphyry or the rhyolite of Red Mountain, near by on the east. The solutions were probably sulphurous and acidic, and the process was attended by some silicification. The deposition apparently took place in two periods or else during the deposition the rock was crushed and sheared, after which the veinlets traversing the earlier alunite bodies were deposited in the fractures. However, Ransome[1] and others have shown that alunite may be formed by very different processes, among which is the action on feldspar, as held by De Launay, or on sericite away from free oxygen, as held by Lindgren,[2] of downward-percolating meteoric waters charged with sulphuric acid by the oxidation of pyrite. In the locality here described the pyritic and highly sericitized character of the weathered porphyry admirably fulfills the conditions requisite for the formation of the alunite by the meteoric process.

In prospecting for alunite as suggested by Butler and Gale[3] it is well to examine (1) the so-called kaolin and talc deposits and also those of jarosite, associated with the feldspathic rocks in the oxidized zone; (2) phases of the Tertiary volcanic rocks containing potassium and aluminum silicates, in places where, as along fissures, they have suffered propylitic alteration by hydrothermal solutions and contain pyrite or chalcopyrite; (3) supposed spar, talc, or kaolin veins, especially in or near Tertiary volcanic rocks, whether associated with metallic veins or not.

Butler and Gale[4] give the following simple field test for the mineral alunite, suggested by W. T. Schaller:

Boil the powdered sample with water or with hydrochloric acid for several minutes; after allowing the powder to settle pour off the liquid and repeat the operation to insure the removal of all soluble sulphates. Dry the powder and heat to a dull red. Again boil in water and, after settling, pour off some of the clear liquid. To this add a small fragment or a solution of barium chloride. If the mineral is alunite, a heavy white precipitate will form. To be sure that the water used in this test does not contain sulphates in solution, it should be tested with barium chloride, and if it gives a marked precipitate it can not be used. For this test all that is required that is not included in a miner's or prospector's outfit is a little barium chloride, which can be carried in a small bottle or cartridge.

[1] Op. cit., p. 132.

[2] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 119–120, 169, 193–194.

[3] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912, pp. 61–63.

[4] Idem, p. 63.

ALUNITE AT BOVARD, NEVADA.

By Frank C. Schrader.

INTRODUCTION.

Newly recognized occurrences of the mineral alunite continue to be reported from time to time, most of them revealed during the course of regular geologic studies in mining districts by members of the Geological Survey. The possible economic value of such deposits as a source of potash and of alumina makes them of more than purely mineralogic interest. During a brief visit to the Bovard district, Nevada, in the autumn of 1911 the writer collected some specimens of ore and gangue minerals, and later office study of these specimens has disclosed a new and somewhat unusual occurrence of the mineral alunite. The specimens were obtained at the Gold Pen mine and the Valley View prospect, and similar deposits were observed in two other prospects in the vicinity of the Valley View.

LOCATION AND MEANS OF ACCESS.

Bovard is a small mining district about 2 miles square in Mineral County, in southwestern Nevada. It is 17 miles south of Rawhide and about 20 miles northeast of Thorne, one of the nearest railway stations, on the Nevada & California Railroad (Southern Pacific system). Generally, however, travelers leave the railroad at Schurz, making the trip by way of Rawhide, a total distance of about 50 miles, over a better road, which is feasible for automobiles.

The district, as shown on the map of the Hawthorne quadrangle published by the United States Geological Survey, lies on the northeast slope of the Gabbs Valley Range between elevations of 4,800 and 6,600 feet. It is in a region of Tertiary volcanic rocks whose exposed section is nearly 2,000 feet in thickness. These rocks dip gently to the northeast and are underlain by highly disturbed Paleozoic limestone.

THE ALUNITE.

General character.—Alunite is a hydrous sulphate of aluminum and potassium, having the formula $K_2O.3Al_2O_3.4SO_3.6H_2O$. In its pure condition, which is rare in nature, it contains 11.4 per cent of potassa (K_2O), 37 per cent of alumina (Al_2O_3), 38.6 per cent of sulphuric anhydride (SO_3), and 13 per cent of water (H_2O).

The alunite at Bovard occurs in the form of vertical tabular sheets in fissures in the Tertiary volcanic rocks, especially the rhyolite, and in the Paleozoic limestone. The fissures form a system which trends northwest and southeast through the district, and they contain gold and silver bearing veins of the late Tertiary metallogenetic epoch. The gangue consists chiefly of quartz and brecciated rock, mostly rhyolite, much of which has been silicified and its minerals metasomatically replaced by infiltrated quartz. In a few places the quartz exhibits a laminated structure and is pseudomorphic after an earlier gangue spar mineral, calcite or barite.

In the croppings and oxidized zone the deposits are stained with or contain considerable limonite, hematite, chloropal, calcite, psilomelane, and some ocher-yellowish mineral that is utahite or perhaps jarosite. Locally they are sparingly streaked bluish with molybdenite stain. Adularia is probably associated with the pseudomorphic quartz.

The alunite occurs in the vicinity of the metalliferous veins, between well-defined walls, and is apparently of later origin than the ores. The occurrence of the alunite in association with the rhyolite is, to speak broadly, geologically normal for this part of the country, for most of the known occurrences of alunite in the Western States are in the Tertiary volcanic rocks,[1] from which in most camps the alunite has apparently been derived. This, however, seems to be the first instance reported of alunite in Paleozoic limestone or any other sedimentary rock. Such a mode of occurrence is not surprising, however, for there is no good reason why alunite should not be present in fissures, fractures, and bedding planes of sedimentary strata lying near alunite-bearing volcanic rocks which may supply the requisite materials.

The true character of the alunite was not recognized in the field, and little positive information can be given as to the actual extent of the deposits.

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[1] Cross, Whitman, On alunite and diaspore from the Rosita Hills, Colorado: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 466–475.

Adams, G. I., The Rabbit Hole sulphur mines, near Humboldt House, Nev.: Bull. U. S. Geol. Survey No. 225, 1894, p. 500.

Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 314.

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Hill, R. T., Camp Alunite, a new Nevada gold district: Eng. and Min. Jour., vol. 86, 1908, pp. 1203–1206.

Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: Prof. Paper U. S. Geol. Survey No. 66, 1909, pp. 129–139, 193.

Larsen, E. S., Alunite in the San Cristobal quadrangle, Colorado: Bull. U. S. Geol. Survey No. 530, 1913, pp. 179–183.

Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912, pp. 61–63.

Gold Pen.—The Gold Pen mine is in the northern part of the Bovard district, about half a mile north of the Bovard mine. Both mines are apparently on the same gold-bearing quartz vein, which dips steeply to the east.

At the Gold Pen there are about 400 feet of underground workings, including a shaft 120 feet deep. The mine has produced considerable rich gold ore. The country rock is a pale-reddish fine-grained or nearly aphanitic rhyolite which belongs in the upper part of the local geologic section. It consists chiefly of a cryptocrystalline or felsitic to glassy groundmass, in which are a very few scarcely megascopic crystals of quartz and orthoclase and a little apatite. The rock is much altered, the feldspar being changed to sericite, kaolin, quartz, and secondary feldspar.

The vein is of the fault-breccia type and is from 3 to 10 feet in width. It is composed of finely comminuted quartz, rhyolite, and other fragments all firmly cemented. The rock constituents are largely silicified and replaced by quartz. The vein and ore commonly show megascopic particles of free gold. The vein, as seen in the upper workings, is separated from its walls by sheets of whitish, consolidated, rocklike material, locally called "dry bone," from 3 inches to a foot or more wide.[1] A partial analysis (No. 1 in the following table) of a specimen of this "dry bone" shows it to be fairly pure alunite.

Except that it is a little low in SO_3, the analysis compares favorably with the analyses of selected samples from the deposit at Marysvale, Utah (Nos. 3 and 4), and of a sample from Red Mountain, Colo. (No. 5), and with the theoretical composition of the mineral alunite (No. 6).

Analyses of alunite.

	1	2	3	4	5	6
Al_2O_3	36.0	38	37.18	34.40	39.03	37.0
Fe_2O_3			Trace.	Trace.		
SO_3	33.50	38	38.34	36.54	38.93	38.6
P_2O_5			.58	.50		
K_2O	(a)	3	10.46	9.71	4.26	11.4
Na_2O		6	.33	.56	4.41	
H_2O+			12.90	13.08	13.35	13.0
H_2O-			.09	.11		
SiO_2		None.	.22	5.28		
Insoluble					.50	
	69.50	85	100.10	100.18	100.48	100.0

a Gives strong qualitative tests for potassium.

1. Gold Pen mine, Bovard district, George Steiger, analyst.
2. Valley View prospect, Bovard district, George Steiger, analyst.
3, 4. Marysvale, Utah. Butler, B. S. and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912, p. 8.
5. Red Mountain, Colo. Hurlbut, E. B., on alunite from Red Mountain, Ouray County, Colo.: Am. Jour. Sci., 3d ser., vol. 48, 1894, pp. 130-131.
6. Theoretical composition. Dana, E. S., System of mineralogy, 6th ed., p. 974.

[1] Since this paper was put in type William Raines has reported that the width is in places at least 2½ feet.

The alunite in its relation to the vein and the wall rock at the Gold Pen mine is suggestive of gouge, but it is practically free from crushed rock, clay, quartz, and other materials common to gouge, though in places a few grains of quartz were noted. The alunite is massive and aphanitic. It has a porcelain-like appearance, a hackly or conchoidal fracture, and a hardness of about 4.

Valley View.—The Valley View prospect is in the southern part of the Bovard district, nearly a mile from the Gold Pen mine. It is in a small irregular area, about a fourth of a mile in diameter, of dark-blue or gray Paleozoic limestone which is locally the basal member of the geologic section. The limestone is medium to heavy bedded and strikes in general N. 75° W., with vertical or steep dips to the south. It is folded, faulted, slickensided, intruded by dikes of the surrounding overlying rhyolite, and in places silicified or silicated.

The alunite occurs in a fissure in the limestone. It is exposed in a 30-foot drift, known as the lower tunnel, on the Valley View No. 2 claim. Here, also, as at the Gold Pen mine, the mineral is found as a vertical sheet or vein in the east wall of the drift. It is a structureless or massive white substance, which extends the whole length of the drift and has a thickness of about 18 inches. This drift is situated near the northeast contact of the limestone with the rhyolite. Except for some blue limestone, most of which is silicified and very hard, the drift is almost wholly in oxidized material consisting of a blackish mixture of psilomelane, limonite, and hematite.

The partial analysis of this material, No. 2 on page 353, shows the mineral to be a relatively pure alunite nearly free from silica. A distinctive feature shown by the analysis is its high sodium content, which according to W. F. Hillebrand and S. L. Penfield[1] makes the mineral a natroalunite.

Apparently the highest percentage of sodium in alunite hitherto recorded in the literature is that noted by Hurlbut in the alunite from Red Mountain, Colo., the analysis of which is No. 5 in the accompanying table and shows 4.41 per cent. Alunite containing 4.32 per cent of sodium is reported by Cross[2] from the Rosita Hills, Colo. At Vindicator Mountain, Goldfield, Nev., Ransome[3] noted sodium-bearing alunite in which the molecular ratio of soda to potash is as 40 to 45.

[1] Clarke, F. W., and others, Contributions to mineralogy from the United States Geological Survey: Bull. U. S. Geol. Survey No. 262, 1905, pp. 38–40.

[2] Cross, Whitman, Am. Jour. Sci., 3d ser., vol. 41, 1891, p. 473.

[3] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 131.

The alunite of the Valley View prospect is very close-grained but not hard. It resembles kaolin or chalk and may be pulverized between the fingers to a fine flourlike powder, which, much like that of talc or graphite, is smooth to the feel.

Locally the deposit shows streaks of buff or gray, often with a reddish tinge on the slickensided surfaces. To the finger the colored material is as smooth as the white and is apparently nearly as pure.

The deposit is separated from the limestone country rock by a considerable thickness of earthy oxides of iron and manganese on either side.

The deposit at this place was not traced far beyond the drift by which it is opened, but so far as observed the vein shows no indication of diminution or pinching.

Other occurrences.—About 300 feet south of the Valley View prospect and about 200 feet higher up the hillside a 30-foot tunnel exposes some material which apparently is very impure alunite. The deposit is on a minor fault fissure in limestone, close to a contact with intrusive rhyolite. The fissure contains fragments of impure and altered limestone, oxides of iron and manganese, and a substance believed to be alunite, which for the most part appears to have replaced limestone.

At the Mohawk, a prospect 900 feet east of the Valley View, a shallow cut has been excavated for 16 feet along the contact of limestone with overlying rhyolite, exposing material similar to that just described. The limestone here dips 80° S. and the deposit pitches southeastward into the ridge.

Microscopic character.—The powder of the alunite from the Gold Pen mine and Valley View prospect, when examined under the microscope with high power, is seen to be composed of very fine whitish or colorless crystalline grains with the rhombohedral habit of alunite. The grains have a weak birefringence and their refractive index as determined by E. S. Larsen is 1.567. The grains are too small for the further determination of their optical properties. The crystalline form is best shown in the alunite from the Valley View prospect. The powder also contains a few minute hexagonal scales which apparently are likewise alunite.

CONCLUSIONS.

As little is known of the actual extent of the alunite of the Bovard district, no prediction of its possible commercial value is justified. Furthermore, as a source of potash the occurrence is not, from the evidence at hand, to be considered promising. The deposit in the Valley View prospect, although it may be assumed to represent a considerable quantity of material, has been shown to consist of a potassium-sodium alunite in which the potash content probably does not run high enough to be of value by itself. As to the possibility of its value as a source of alumina there is little precedent to afford a basis for an opinion. A pure alumina free from silica, if it could be derived in considerable quantity from such a deposit, might possibly prove of sufficient value for the manufacture of the metallic aluminum to justify its extraction and treatment, but this suggestion is put forth rather as a possibility than as an estimate of value which the deposit is believed to represent. Suggestions for prospecting are given on page 350.

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 (except the folio) may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the folio only from the Director of the Survey.

BURCHARD, E. F., Bauxite and aluminum: Mineral Resources U. S. for 1906, 1907, pp. 501–510. 50c.

——— Fluorspar and cryolite in 1912: Mineral Resources U. S. for 1912, 1913.

BUTLER, B. S., and GALE, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. 511, 1912.

CANBY, H. S., The cryolite of Greenland: Nineteenth Ann. Rept., pt. 6, 1898, pp. 615–617.

HAYES, C. W., Bauxite: Mineral Resources U. S. for 1893, 1894, pp. 159–167. 50c.

——— The geological relations of the southern Appalachian bauxite deposits: Trans. Am. Inst. Min. Eng., vol. 24, 1895, pp. 243–254.

——— Bauxite: Sixteenth Ann. Rept., pt. 3, 1895, pp. 547–597. $1.20.

——— The Arkansas bauxite deposits: Twenty-first Ann. Rept., pt. 3, 1901, pp. 435-472. $1.75.

——— Bauxite [in Rome quadrangle, Georgia-Alabama]: Geol. Atlas U. S., folio 78, 1902, p. 6. 5c.

——— The Gila River alum deposits: Bull. 315, 1907, pp. 215–223. 50c.

HUNT, A. E., Mineral Resources U. S. for 1892, 1893, pp. 227–254. 50c.

LARSEN, E. S., Alunite in the San Cristobal quadrangle, Colo.: Bull. 530, 1913, pp. 179–183.

PACKARD, R. L., Aluminum and bauxite: Mineral Resources U. S. for 1891, 1892, pp. 147–163. 50c.

——— Aluminum: Sixteenth Ann. Rept., pt. 3, 1895, pp. 539–546. $1.20.

PHALEN, W. C., Bauxite and aluminum in 1912: Mineral Resources U. S. for 1912, 1913.

SCHNATTERBECK, C. C., Aluminum and bauxite: Mineral Resources U. S. for 1904, 1905, pp. 285–294. 70c.

SPURR, J. E., Alum deposits near Silver Peak, Esmeralda County, Nev.: Bull. 225, 1904, pp. 501–502. 35c.

STRUTHERS, J., Aluminum and bauxite: Mineral Resources U. S. for 1903, 1904, pp. 265–280. 70c.

STRUCTURAL MATERIALS, ETC.

THE ABERDEEN GRANITE QUARRY NEAR GUNNISON, COLORADO.

By J. FRED. HUNTER.

INTRODUCTION.

During the summer of 1912, in the course of the mapping of the geology and, in particular, the granites and gneisses of the Uncompahgre quadrangle, Colorado, the writer had occasion to make a hasty examination of the Aberdeen granite quarry, which lies about three-quarters of a mile east of the quadrangle. Although there are many granite quarries and much granite available for building stone within short distances of the larger towns of Colorado, gray granite is by no means so common as other varieties. This fact adds interest to the occurrence here described.

The Aberdeen granite quarry is located in Gunnison County, on South Beaver Creek, about 4 miles from the point where that stream empties into Gunnison River. It is 11 miles from the town of Gunnison and about 5½ miles from a siding on the Denver & Rio Grande Railroad, from which the stone has been shipped in recent years.

The quarry is owned jointly by F. G. Zugelder, of Gunnison, Peter F. Bossie, and Gettis & Seerie, of Denver. The quarry site was patented in 1890 as placer claims, and includes in all 120 acres, in secs. 4 and 5, T. 48 N., R. 1 W.

HISTORY.

From Mr. Fred Zugelder, of Gunnison, the following brief account of the history of the quarry was obtained.

The quarry was first worked in July, 1889, when Gettis & Seerie began taking out stone for the State capitol at Denver. From this time until 1892 they worked an average of 60 men and took out about 280,000 cubic feet of stone. This was by far the largest and longest operation that the quarry has known. The granite was loaded at the quarry, there being at that time a spur up South Beaver Creek. The stone had to be transferred, however, from the narrow-gage to the standard-gage cars at Salida.

Since this period of activity the quarry has been worked only sporadically. From 1892 until 1895 a small amount of monumental stock was quarried. During 1905 stone was quarried for the steps of the State capitol. In 1908 Mr. Zugelder took out 3,500 cubic feet, and in 1911–12 Mr. Bossie quarried about 3,000 cubic feet for the State Museum building in Denver. The last work was done in July, 1912, and the quarry is now idle. In all nearly 290,000 cubic feet of stone has been quarried.

GEOLOGIC RELATIONS.

The quarry granite is part of a broad dikelike mass intruding pre-Cambrian gneiss. This body is one of many similar masses of varying sizes and shapes intruding the pre-Cambrian metamorphic rocks approximately parallel to their schistosity, which strikes N. 50–60° W. in this vicinity. The bodies of this type of granite are very numerous in a zone running northwestward through the northeast corner of the Uncompahgre quadrangle. They are characteristically lacking in persistency, and grade laterally as well as longitudinally from granite with numerous inclusions of gneiss to gneiss highly injected with granite. The granite has been injected into the highly foliated gneiss along the planes of schistosity in all manner of ways and in bodies of all shapes and sizes. However, no very large single bodies were observed in the region studied, to the northwest of the quarry. Indeed, the largest body so far seen is the one in which the quarry is located.

This mass is in places over a quarter of a mile wide and can be followed for nearly 2 miles in a N. 50° W. direction from the quarry. How far it extends to the southeast is not known. In many places northwest of the quarry the granite of this band includes considerable gneiss. This condition makes it extremely difficult to find large enough bodies for quarrying and has influenced the location of the Aberdeen quarry at so great a distance from the railroad.

THE GRANITE.

PETROGRAPHIC CHARACTER.

The rock is a soda-rich granite and is known in the trade as gray granite. It approaches a quartz diorite in composition. The thick sprinkling of black biotite through the clear transparent quartz and white, more opaque feldspar, gives the general gray appearance. The rock is entirely crystalline, of medium grain and even texture. The individual crystals average from 2 to 3 millimeters in diameter, few being larger than 7 millimeters.

In thin section the rock is seen to be allotriomorphic—that is, almost all the individual minerals which compose it are without definite crystal outline and have irregular boundaries. The texture is that usual to a granite, and the individual minerals, although varying somewhat in size, show all intermediate gradations from the smallest to the largest.

The essential mineral constituents, in descending order of abundance, are plagioclase of the composition of oligoclase, quartz biotite, and potash feldspar (microcline and orthoclase). The potash feldspar is very subordinate, comprising less than 5 per cent of the rock. The accessory minerals are magnetite, apatite, epidote, calcite, and titanite.

An estimate of the mineral percentages of the rock by the Rosiwal method gave the following results: Quartz, 36; feldspar, 51; biotite, 12; accessory minerals, 1.

PHYSICAL CHARACTER.

The granite is hard and compact and is said to work easily. It takes a good polish, becoming slightly darker than on fracture surfaces. It is said to be good for bush-hammer work and has been used for monumental stone. For the latter purpose, and particularly for inscriptions, the color, susceptibility to polish, and contrast between cut or hammered and polished surfaces, are properties of chief economic importance. Merrill[1] has explained the cause of these contrasts very satisfactorily:

> The impact of the hammer breaks up the granules on the immediate surface, so that the light falling upon it is reflected, instead of absorbed, and the resultant effect upon the eye is that of whiteness. The darker color of a polished surface is due merely to the fact that, through careful grinding, all these irregularities and reflecting surfaces are removed, the light penetrating the stone is absorbed, and the effect upon the eye is that of a more or less complete absence of light, or darkness. Obviously, then, the more transparent the feldspars and the greater the abundance of dark minerals, the greater will be the contrast between hammered and polished surfaces. This is a matter worthy of consideration in cases where it is wished, as in a monument, to have a polished die, surrounded by a margin of hammered work to give contrast.

The abundance of black mineral and the transparency of the quartz and plagioclase feldspar in the granite are very significant in this connection.

The granite has a decided rift (running approximately N. 60° W. in the mass), along which it slabs easily. Physical tests of the granite were made by E. C. Rhody, a student in the college of engineering of the University of Colorado, with the following results:

Compressive strength	pounds per square inch	14,340
Modulus of rupture	do	2,465
Proper specific gravity		2.71
Apparent specific gravity		2.70
Ratio of absorption	per cent	.17
Porosity	do	.46
Weight per cubic foot	pounds	169

[1] Merrill, G. P., The physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898, p. 64.

In outcrops the granite shows considerable weathering near the surface. In this process it becomes rougher, the quartz and feldspar standing out more prominently, and the rock takes on a brownish and more somber tone. There are, as a rule, innumerable cracks and minor joints where the rock has been long exposed to surface weathering. These, however, are superficial and apparently do not extend more than a short distance from the surface. The face of the quarry shows fresh, unaltered rock with few joints or cracks. Quarried rock which has lain out in the weather for several years shows no sign of staining or disintegration. The granite of the State capitol at Denver, which came from this quarry, is said to show no evidence of weathering after 20 years' exposure to the weather.

CONDITIONS AND DEVELOPMENT.

The Aberdeen quarry is situated along the north and east sides of South Beaver Creek at an elevation of about 8,000 feet above sea level. The workings, which are of the sidehill type, extend for several hundred yards along the creek. There is no overburden and the creek here has steep, canyonlike slopes so that it has been necessary only to remove the talus from the foot of the cliffs and a small amount of weathered surface rock to get into a face of fresh, unaltered granite. At the upper end of the quarry, where the workings have been carried on most extensively, the face is 50 feet high for a distance of 100 feet. From this space most of the rock has been taken, although a much larger working face would be available if needed. This face shows massive rock with but little jointing, so that blocks of almost any size can be obtained. There is an irregular jointing nearly parallel to the face of the quarry. A single well-marked joint plane runs diagonally across the face of the quarry, dipping 45° E. The rock at the face is fresh and clean, with no sign of staining.

Conditions of quarrying are favorable, in that the bottom of the quarry is far enough above the bed of the stream to be well drained and at the same time afford a ready means of loading. The quarry equipment has been largely dismantled. At present there remain a derrick, a boiler and boiler house, some track, several large frame houses, and a few cabins. The railroad along the creek has been torn up.

ORNAMENTAL MARBLE NEAR BARSTOW, CALIFORNIA.

By Robert W. Pack.

INTRODUCTION.

In December, 1912, while engaged in a reconnaissance of a portion of the Mohave Desert north of Barstow, Cal., the writer saw specimens of very attractive ornamental marble which had been obtained at a recently discovered deposit in the mountains south of town, and through the kindness of Messrs. E. T. Hillis and P. M. Le Sage, owners of the claims on which the marble occurs, he was able to spend a couple of hours on the property. The following notes are based on the hasty and necessarily superficial examination this brief time permitted.

Barstow is a settlement of about 800 or 900 persons in western San Bernardino County, Cal. It is situated on Mohave River, in the central part of the Mohave Desert, approximately 140 miles east of Los Angeles by rail. Two railroads pass through it, the San Pedro, Los Angeles & Salt Lake Railroad and the Atchison, Topeka & Santa Fe Railway, Barstow being the junction of the San Francisco and Los Angeles lines of the latter road.

The marble deposit occurs in the northern part of a mountain group which lies between the San Bernardino Range on the south and Mohave River on the north. This group, which is known as the Granite Mountains, comprises a number of rugged, almost treeless ridges which rise abruptly from the desert floor, and which have no definite system of orientation or arrangement, being really a collection of more or less isolated peaks and ridges. The marble is found on the north flank of one of these ridges, locally known as Stoddard Peak Ridge. It is about 15 miles due south of Barstow, in an unsurveyed part of T. 7 N., R. 2 W., San Bernardino base and meridian. A good but rather circuitous road some 22 miles in length extends from Barstow to a point within about a mile of the deposit. The closest railroad point is Cottonwood siding, on the road to Los Angeles, which is said to be about 14 miles distant by road. Stoddard Well, 6 or 8 miles from the deposit on the road to Barstow, furnishes the only water in this vicinity.

CHARACTER AND AGE OF THE ROCKS.

As their name implies, the Granite Mountains are formed largely of granitoid rocks. These rocks are associated with various schists, gneisses, quartzites, crystalline limestones, and some less altered sedimentary and igneous rocks. Metamorphic and igneous rocks of this general type are widely distributed over southeastern California and the neighboring parts of Nevada and Arizona, but as yet those occurring in the central part of the Mohave Desert have received scant study, and very little is known as to their age or their correlation with the rocks occurring in better-known regions. About 70 miles north of Barstow, in the Funeral and Kingston ranges, Paleozoic rocks of various kinds rest upon nonfossiliferous rocks that are believed to be pre-Cambrian.[1] In the southeastern part of the desert, 100 miles to the east, Cambrian rocks rest upon an earlier granite.[2] In the San Bernardino Range to the south various metamorphic rocks of unknown age are intruded by igneous rocks.[3] Altered sedimentary rocks that are believed, on the evidence of a few poorly preserved fossils, to be Carboniferous, as well as some probably older schists and granites, occur in the Randsburg region, some 30 miles northwest of Barstow.[4]

The only attempt to correlate the metamorphic and igneous rocks in the Granite Mountains with similar rocks in better known regions is that made by Hershey,[5] who briefly describes certain metamorphosed sedimentary rocks south of Barstow along the Los Angeles line of the Santa Fe Railway, and correlates them with Lower Cambrian rocks in the White Mountains of Inyo County described by Walcott. This correlation is based entirely on the general similarity in the degree of metamorphism and mode of occurrence of the rocks at the two places and can not be considered as definitely established.

THE MARBLE.

Occurrence.—The marble occurs on the east flank of a spur ridge which extends toward the north almost at right angles to the trend of Stoddard Peak Ridge. The deposit consists of a number of beds of brecciated mottled green and white marble which vary in thickness from a few inches up to 10 or 12 feet and possibly even to 20 feet. Interstratified in alternate layers with the beds of marble are

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1 Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 33, 179, 181. Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: Bull. U. S. Geol. Survey No. 200, 1902, p. 14. Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903, pp. 187-200.

2 Darton, N. H., Discovery of Cambrian rocks in southeastern California: Jour. Geology, vol. 15, 1907, pp. 470-475.

3 Mendenhall, W. C., unpublished notes.

4 Hess, F. L., Gold mining in the Randsburg quadrangle, California: Bull. U. S. Geol. Survey No. 430, 1910, pp. 23-47.

5 Hershey, O. H., Some crystalline rocks of southern California: Am. Geologist, vol. 29, 1902, pp. 286, 287.

hard siliceous detrital rocks which vary in color from light yellow-green to greenish black. These siliceous rocks were evidently originally arkose sandstones or shale, but they have been altered and under the microscope show a slightly schistose structure and an abundance of greenish sericite. Both the marble and the interstratified siliceous rocks form prominent ragged outcrops which are traceable for more than 2,500 feet. Where best developed the marble occurs through a stratigraphic thickness of 200 feet or more. The beds strike approximately north and south along the spur ridge and dip westward into it. Near the center of the spur, where a small cut has been opened, the dip is approximately 20°, but in general it is probably somewhat higher. At the base of the succession of alternating beds of brecciated marble and altered detrital rocks is a bed of gray crystalline limestone a few feet thick. This bed, although considerably fractured, does not exhibit the brecciation characteristic of the marble nor does it show the slightest trace of greenish color.

Character and composition.—The marble is essentially a brecciated white crystalline limestone recemented by a greenish calcareous cement. The brecciated fragments are angular and vary in size, some of them being as much as 6 or 8 inches in length. Some of the fragments, particularly the larger ones, retain their original white color and form a sharp contrast to the inclosing greenish matrix. Most of them, however, are at least partly colored, commonly having an outer greenish rim. Many of the smaller fragments are stained throughout and assume a greenish color similar to that of the matrix, but lighter in tone. Many of the unstained fragments are finely crystalline, dense, and of a dead-white color; others are more coarsely crystalline and appear semitranslucent on a polished surface. In general effect the marble is mottled green, black, and white, but this appearance varies greatly, owing to the irregular size and staining of the brecciated fragments, to their irregular spacing, and to differences in the tone of the cementing material. The finely brecciated material is usually a mottled light yellow-green, olive-green, and black, with a few small fragments of unstained lime, and is probably the most handsome. In places, owing to a parallel arrangement of the longer axes of the brecciated fragments, the marble has a somewhat banded appearance. Small crystals of pyrite, barely visible to the unaided eye, occur in scattered bunches or small stringers. So far as observed the marble is free from veins or bands of silica. It is reported to cut easily and takes a very fair polish.

Under the microscope the marble is seen to be entirely recrystallized. The principal impurity is a feebly double-refracting mineral, probably either chlorite or serpentine, which occurs in abundant minute particles in the colored portions of the stone. Tremolite is also present, but in far less amount.

The following analyses were made by George Steiger, of the United States Geological Survey. The first represents a sample of the more finely brecciated marble in which the original white fragments as well as the matrix have a greenish color. The second represents a sample of the unbrecciated gray limestone which occurs below the marble.

Analyses of limestones from beds near Barstow, Cal.

	1	2		1	2
SiO_2	21.63	2.02	H_2O-	0.17	0.02
Al_2O_3	3.86	1.48	H_2O+	6.07	.51
Fe_2O_3	.80	None.	TiO_2	.26	None.
FeO	1.13	.30	CO_2	20.35	42.41
MgO	19.17	7.56	P_2O_5	.05	None.
CaO	26.18	45.89	Cr_2O_3	None.	None.
Na_2O	None.	.02			
K_2O	None.	.23		99.67	100.44

Originally the beds of greenish marble were probably grayish limestone, somewhat similar to that now exposed at the base of the section. These beds were brecciated and recemented by a calcareous cement obtained from percolating solutions which contained, besides the lime, considerable amounts of magnesia and silica, probably derived from the interstratified arkosic beds. The magnesia shown in the analysis of the greenish marble probably occurs in part as dolomite in the brecciated fragments. The remainder is mainly in the matrix in combination with the silica in the form of chlorite or serpentine.

Weathering.—The marble shows very little decomposition from weathering. Usually the rock is affected to a depth of only a fraction of an inch, and when it is chipped fresh unweathered stone appears. The brecciated fragments weather somewhat more easily than the matrix, and the outcrops have a very pitted appearance. Many of the fragments have a thin dark coating formed largely of chlorite or serpentine, which weathers out, leaving deeply impressed grooves between the fragments and the inclosing matrix.

Jointing.—The marble is rather extensively jointed, and the surface outcrops show very few unbroken blocks more than 3 feet in diameter. The joints, as nearly as may be judged from the surface exposures, have no systematic distribution or arrangement. No regularity which might be of service in the extraction of the stone was observed. Many of the joints unquestionably disappear at moderate depth, and although the seam may continue it is filled and recemented by lime. This is well shown in a small cut driven about 20 feet into the hill near the center of the deposit, where several large blocks, one measuring roughly 6 by 7 by 9 feet, apparently free from flaws, were obtained. Besides the jointing of this type several small cross faults have offset the beds, in places bringing the marble into juxtaposition along the strike with the interstratified siliceous detrital rock. Such a cross fault forms the south wall of the small cut mentioned above.

Utilization.—The deposit is practically undeveloped. The surface showings are promising and are worthy of careful exploratory work. In the central and northern parts of the deposit the beds of marble appear to be several feet thick, and good-sized blocks can probably be extracted, but toward the south the marble and the siliceous rock occur in alternate beds only a few inches thick. The feature that will interfere most seriously with the exploitation of the deposit is the fracturing. As has been pointed out, there seems to be no regularity in the jointing that would aid in the extraction of the material. Many of the joints evidently disappear a few feet below the surface, but others are probably more persistent, and along some there has been movement resulting in an offsetting of the beds. It will take careful detailed work, including both an examination of the outcrops and systematic core drilling or excavating, to determine just how seriously the marble is fractured and how large blocks may be obtained. The marble dips at a fairly low angle into the hill, and considerable dead work will always be necessary. One point very much in its favor is that the marble is an ornamental stone of unique and pleasing appearance, and in consequence a relatively small block would be commercially valuable.

OTHER DEPOSITS OF LIMESTONE.

Other deposits of limestone occur in this vicinity, but so far as known they do not show the brecciation characteristic of the greenish marble. About half a mile north of the marble deposit is a high, long ridge almost barren of vegetation, trending approximately east and west. The crest of this ridge is determined by a thick bed of gray limestone which may easily be followed by the eye. This outcrop was not visited, but according to Mr. Le Sage it is composed of gray limestone exactly like that found at the base of the section in which the marble occurs. He also reports that the limestone is traceable for over three-quarters of a mile and that it is in contact with granitic rocks, none of the altered detrital rocks similar to those bedded with the marble being present.

About 2 miles southwest of the deposit of brecciated marble, in, it is said, sec. 28, T. 7 N., R. 2 W., is an old excavation known as the Gem quarry, the Kimball mine, or the Verde Antique Marble quarry.

This quarry is briefly described in a State bulletin.[1] It was opened 15 years or more ago and has been worked for short periods at several different times. Owing to the fractured condition of the stone and the impossibility of extracting blocks of reasonable size, it was finally abandoned and has now been idle for several years. Specimens of the rock now in the National Museum were examined. It is a mottled or wavy serpentinous limestone, usually light yellowish green in color and unbrecciated, and is entirely different from the green brecciated marble here described.

[1] The structural and industrial materials of California: Bull. California State Min. Bur. No. 38, 1906, pp. 147–148.

CLAY IN NORTHEASTERN MONTANA.

By C. M. Bauer.

Field work.—During July and August, 1912, several townships in the vicinity of Plentywood, Mont., were geologically examined, principally for the purpose of determining the quality and thickness of the lignite beds of that area. While this work was being done interest was directed to a white bedded deposit that had been used locally for plaster and mortar. Visits to several pits from which the material had been excavated seemed to indicate that it was a fair-grade clay. Samples were collected from several places near Redstone and the locations of prospects were determined. The accompanying map (Pl. VIII) gives these locations and shows the approximate position of the outcrop.

Geology.—The clay bed is a part of the Fort Union formation and is therefore of Tertiary age. This formation consists of stratified materials, principally shale, clay, and sandstone, with local thin lenses of limestone and beds of lignite. The strata in this field have a southeasterly dip of about 19 feet to the mile.

Extent and character of the bed.—The known extent of the bed is about 18 miles east and west and about 8 miles north and south, but it probably has a much wider distribution.

On a high hill about a mile southwest of Redstone and a quarter of a mile west of the Bergh lignite mine is an outcrop of the clay bed. In this place (locality No. 1 of the accompanying map) it is 8 feet thick and has gray shale above and below. It is massive and homogeneous through the entire thickness. As the quality here is representative of that in the western half of the field a sample was collected and sent to A. V. Bleininger, of the United States Bureau of Standards, for examination. The report on this sample may be found below under the heading "Properties of the clay." West of this point the clay bed has been eroded generally.

In sec. 2, T. 35 N., R. 52 E., is a pit (locality No. 2) from which clay has been taken for local use. At this locality the bed is 4 feet thick and very similar in quality to that at locality No. 1. At locality

No. 3, in sec. 1 of the same township, the following section of the bed was measured:

Section at locality No. 3, sec. 1, T. 35 N., R. 52 E.

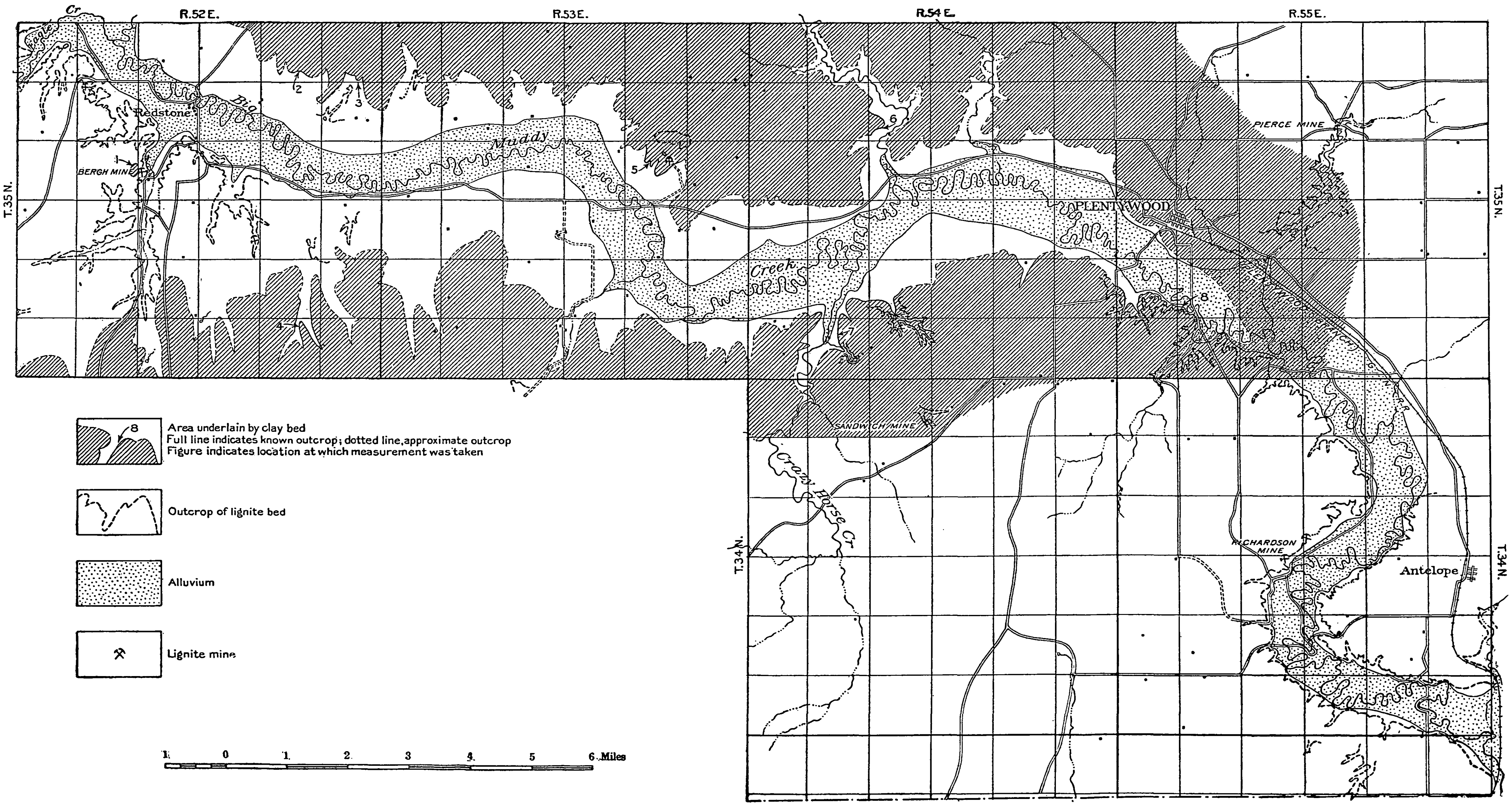
	Ft.	in.
Sandstone.		
Limestone, siliceous	2	6
Clay, blue and yellow, alternating layers	5	
Shale, gray	4	
Shale, yellow, arenaceous		10
Clay, white, hard	1	10
Shale, yellow		10
Clay, white, hard	4	2
Shale, brown.		

Locality No. 4, in sec. 35, T. 35 N., R. 52 E., is on the outcrop of the bed, but no measurement was obtained here. In the Chalky Buttes, in sec. 14, T. 35 N., R. 53 E., this bed is sandy and separated into several layers by thick partings of sandstone, and the weathering of the clay gives a general white appearance to the neighboring beds.

The bed also outcrops along Plentywood Creek in T. 35 N., R. 54 E., and at locality No. 6 it is 2 feet 10 inches thick but contains a large percentage of sand. On Dick Mann's ranch, along Crazy Horse Creek, the bed is 4 feet 3 inches thick and of fair quality. At locality No. 7 it is only 30 feet above the water in the creek. Another measurement was obtained on the same stratum about a mile south of Plentywood, T. 35 N., R. 55 E. At this point, however, it is 16 feet 8 inches thick and is composed almost entirely of white sandstone. Some of the material from this place was examined and seemed to be chiefly grains of quartz and muscovite. A few hundred yards east of this point, where the road crosses Big Muddy Creek, the dip of the stratum takes it below the level of the flood plain.

Origin of the clay.—The origin of this clay can be attributed to sedimentation in a quiet body of water during the Fort Union epoch. The white color is probably due primarily to subsequent bleaching by waters laden with organic acids which leached through the bed and carried away the more soluble constituents. However, lixiviation was not completed and the whiteness is intensified by the presence of a small amount of lime. Beds of white clay have been noted in the Cypress Hills and along White Mud River in Canada by R. G. McConnell,[1] who states that "The clays and sands have been bleached almost pure white by the action of vegetable débris. * * * Exposures in the distance look like great snow banks. The clays and sands graduate almost imperceptibly one into the other and seldom remain pure for any distance."

[1] McConnell, R. G., Rept. Canada Geol. Survey, 1885, Northwest Territory, p. 28c.



MAP SHOWING LOCATION OF CLAY BED NEAR PLENTYWOOD, MONT.

Properties of the clay.—The character and quality of the clay, as reported by the United States Bureau of Standards, are as follows:

The sample received consisted of lumps of hard clay, gray in color. The clay was ground in a mortar, screened through a 20-mesh sieve, and tempered with water. Small briquets were molded by hand, dried, and burned. The clay developed good plasticity and bonding power and the drying behavior was satisfactory, the dried briquets possessing high tensile strength. The linear drying shrinkage of the clay was 8 per cent.

Briquets of the clay were burned in a natural-gas-fired kiln to different temperature and the following noted:

Temperature.	Color.	Hardness.	Water absorption.
° C.			*Per cent.*
950	Buff	Soft	13.1
1,010	Buff	Soft	13.3
1,070	Buff	Soft	11.8
1,130	Buff	Steel hard	7.5
1,190	Gray	Steel hard	.9
1,250	Gray	Steel hard	.4

The softening point of the clay in an electric furnace was found to correspond to that of standard pyrometric cone 20 (approximately 1,530° C.).

From the above preliminary examination we would say that the material has properties similar to those of a No. 3 fire clay. The temperature at which the clay softens is not sufficiently high to permit its use in the manufacture of refractories. The sample submitted was not large enough to observe the behavior of the plastic clay in flowing through the die of an auger machine. The indications are, however, that the material would be satisfactory in this respect.

The clay appears to be a promising one for the manufacture of common and face brick and possibly drain tile and fireproofing.

The buff color developed by burning would not permit its use in the manufacture of whiteware pottery. However, the clay has properties similar to those used in the manufacture of stoneware.

The clay contains no injurious impurities except in the area south of Plentywood, where it grades into sandstone. It is believed that the quartz sand which is mingled with it in this area could readily be separated by washing and settling. The outcrop of the bed is near the Big Muddy flat, where water can readily be obtained. Wells 25 to 35 feet deep have an abundant flow of water.

Development and utilization.—The development and utilization of this bed have been meager. It has been used locally for plaster and mortar in building walls and chimneys, but it is not a satisfactory material when used in this way. It becomes fairly hard, however, when dried or baked in the sun, but unless it is fired it is readily affected by water. It is believed that the clay could best be used in the manufacture of brick. Crockery and tile could also be made from it, and by the addition of small quantities of iron or other metallic oxides a variety of colors might be obtained.

The outcrop and distribution so far as known are shown on the accompanying map. Owing to the white color of the bed the outcrops are readily detected. In the western part of the area it is exposed on the high hills, but toward the east, because of the eastward dip of the strata, their altitude diminishes, and at a point about a mile south of Plentywood the clay bed disappears beneath the flat of Big Muddy Creek. The overlying bed is a gray shale from 2 to 15 feet in thickness. Perhaps the most desirable spot for mining is in sec. 17, T. 35 N., R. 52 E., where the overburden does not exceed 20 feet. The presence of lignite in the area will aid greatly in the exploitation of the bed and the manufacture of clay products. The outcrop and distribution of the lignite beds of this region are shown on the map. Near the point just mentioned is a lignite mine operated by Olaf Bergh. The lignite bed at the mine is 5 feet 5 inches thick and of fair quality and could be used for firing.

Transportation.—A branch of the Great Northern Railway has recently been extended from Bainville to Plentywood. This opens the way for shipment to many western markets, and though the local demand for the clay products may not be great, the association of lignite and clay, together with the advantages of location and transportation, may make the deposit valuable to the prospective manufacturer.

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.: Bull. 213, 1903, pp. 357–360. 25c.

BAIN, H. F., Notes on Iowa building stones: Sixteenth Ann. Rept., pt. 4, 1895, pp. 500–503. $1.20.

BURCHARD, E. F., Structural materials available in the vicinity of Minneapolis, Minn.: Bull. 430, 1910, pp. 280–291.

——— Structural materials available in the vicinity of Austin, Tex.: Bull. 430, 1910, pp. 292–316.

——— Stone industry in 1912: Mineral Resourses U. S. for 1912, 1913.

BUTTS, CHARLES, Variegated marble southeast of Calera, Shelby County, Ala.: Bull. 470, 1911, pp. 237–239.

COONS, A. T., Slate in 1912; Mineral Resources U. S. for 1912, 1913.

DALE, T. N., The slate belt of eastern New York and western Vermont: Nineteenth Ann. Rept., pt. 3, 1899, pp. 153–200. $2.25.

——— The slate industry of Slatington, Pa., and Martinsburg, W. Va.: Bull. 213, 1903, pp. 361–364. 25c.

——— Notes on Arkansas roofing slates: Bull. 225, 1904, pp. 414–416. 35c.

——— Note on a new variety of Maine slate: Bull. 285, 1906, pp. 449–450. Exhausted. May be found at large public libraries.

——— Commercial qualities of the slates of the U. S. and their localities: Mineral Resources U. S. for 1912, 1913.

——— The granites of Maine: Bull. 313, 1907, 202 pp. 35c.

——— The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: Bull. 354, 1908, 228 pp.

——— The granites of Vermont: Bull. 404, 1909, 138 pp.

——— Supplementary notes on the granites of New Hampshire: Bull. 430, 1910, pp. 346–372.

——— Supplementary notes on the commercial granites of Massachusetts: Bull. 470, 1911, pp. 240–288.

——— The commercial marbles of western Vermont: Bull. 521, 1912, 170 pp.

DALE, T. N., and GREGORY, H. E., The granites of Connecticut: Bull. 484, 1911, 137 pp.

DALE, T. N., and others, Slate deposits and slate industry of the United States: Bull. 275, 1906, 154 pp. Exhausted.

DARTON, N. H., Marble of White Pine County, Nev., near Gandy, Utah: Bull. 340, 1908, pp. 377–380. 30c.

——— Structural materials in parts of Oregon and Washington: Bull. 387, 1909, 36 pp.

——— Economic geology of Richmond, Va., and vicinity: Bull. 483, 1911, 48 pp.

DILLER, J. S., Limestone of the Redding district, California: Bull. 213, 1903, p. 365. 25c.

ECKEL, E. C., Slate deposits of California and Utah: Bull. 225, 1904, pp. 417, 422. 35c.

GARDNER, J. H., Oolitic limestone at Bowling Green and other places in Kentucky: Bull. 430, 1910, pp. 373–378.

HILLEBRAND, W. F., Chemical notes on the composition of the roofing slates of eastern New York and western Vermont: Nineteenth Ann. Rept., pt. 3, 1899, pp. 301–305. $2.25.

HOPKINS, T. C., The sandstone of western Indiana: Seventeenth Ann. Rept.; pt. 3, 1896, pp. 780–787. $1.

——— Brownstones of Pennsylvania: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1025–1043. $1.

HOPKINS, T. C., and SIEBENTHAL, C. E., The Bedford oolitic limestone of Indiana: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1050–1057. $1.

HUMPHREY, R. L., The fire-resistive properties of various building materials: Bull. 370, 1909, 99 pp. 30c.

KEITH, A., Tennessee marbles: Bull. 213, 1903, pp. 366–370. 25c.

KÜMMEL, H. B., and others, Raritan (N. J.) folio (No. 191), Geol. Atlas U. S., 1914. (In press.) 25c.

LEIGHTON, HENRY, and BASTIN, E. S., Road materials of southern and eastern Maine: Bull. 33, Office of Public Roads, U. S. Dept. Agr., 1908. (May be obtained from Department of Agriculture.)

PAIGE, SIDNEY, Marble prospects in the Chiricahua Mountains, Arizona: Bull. 380, 1909, pp. 299–311. 40c.

——— Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 103 pp.

PURDUE, A. H., The slates of Arkansas: Bull. 430, 1910, pp. 317–334.

RIES, HEINRICH, The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut: Seventeenth Ann. Rept., pt. 3 (continued), 1896, pp. 795–811.

SHALER, N. S., Preliminary report on the geology of the common roads of the United States: Fifteenth Ann. Rept., 1895, pp. 259–306. $1.70.

——— The geology of the road-building stones of Massachusetts, with some consideration of similar materials from other parts of the United States: Sixteenth Ann. Rept., pt. 2, pp. 277–341. $1.25.

SIEBENTHAL, C. E., The Bedford oolitic limestone [Indiana]: Nineteenth Ann. Rept., pt. 6, 1898, pp. 292–296.

SMITH, G. O., The granite industry of the Penobscot Bay district, Maine: Bull. 260, 1905, pp. 489–492. Exhausted.

UDDEN, J. A., The oolitic limestone industry at Bedford and Bloomington, Ind.: Bull. 430, 1910, pp. 335–345.

WATSON, T. L., Granites of the southeastern Atlantic States: Bull. 426, 1910, 282 pp.

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 marked with an asterisk and those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. Applications for publications marked with an asterisk (*) should be addressed to the United States Bureau of Standards at Washington. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ADAMS, G. I., and others, Economic geology of the Iola quadrangle, Kansas: Bull. 238, 1904, 80 pp. 25c.

BALL, S. H., Portland cement materials in eastern Wyoming: Bull. 315, 1907, pp. 232–244. 50c.

BASSLER, R. S., Cement materials of the valley of Virginia: Bull. 260, 1905, pp. 531–544. Exhausted.

BURCHARD, E. F., Portland cement materials near Dubuque, Iowa: Bull. 315, 1907, pp. 225–231. 50c.

——— Concrete materials produced in the Chicago district: Bull. 340, 1908, pp. 383–410. 30c.

——— Structural materials available in the vicinity of Minneapolis, Minn.: Bull. 430, 1910, pp. 280–291.

——— Structural materials available in the vicinity of Austin, Tex.: Bull. 430, 1910, pp. 292–316.

——— The cement industry in the United States in 1912: Mineral Resources U. S. for 1912, 1913.

BUTTS, CHARLES, Sand-lime brick making near Birmingham, Ala.: Bull. 315, 1907, pp. 256–258. 50c.

——— Ganister in Blair County, Pa.: Bull. 380, 1909, pp. 337–342. 40c.

CATLETT, C., Cement resources of the valley of Virginia: Bull. 225, 1904, pp. 457–461. 35c.

CLAPP, F. G., Limestones of southwestern Pennsylvania: Bull. 249, 1905, 52 pp.

CRIDER, A. F., Cement resources of northeast Mississippi: Bull. 260, 1905, pp. 510–521. Exhausted.

——— Geology and mineral resources of Mississippi: Bull. 283, 1906, 99 pp.

DARTON, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper 65, 1909, 104 pp.

——— Structural materials in parts of Oregon and Washington: Bull. 387, 1909, 36 pp.

——— Cement materials in Republican Valley, Nebraska: Bull. 430, 1910, pp. 381–387.

DARTON, N. H., and SIEBENTHAL, C. E., Geology and mineral resources of the Laramie Basin, Wyoming: Bull. 364, 1908, 81 pp.

DURYEE, E., Cement investigations in Arizona: Bull. 213, 1903, pp. 372–380. 25c.
ECKEL, E. C., Cement-rock deposits of the Lehigh district: Bull. 225, 1904, pp. 448–450. 35c.
——— Cement materials and cement industries of the United States: Bull. 243, 1905, 395 pp. 65c.
——— The American cement industry: Bull. 260, 1905, pp. 496–505. Exhausted.
——— Portland cement resources of New York: Bull. 260, 1905, pp. 522–530. Exhausted.
——— Cement resources of the Cumberland Gap district, Tennessee-Virginia: Bull. 285, 1906, pp. 374–376. Exhausted. Available for reference in larger public libraries.
——— Portland cement materials of the United States, with contributions by E. F. Burchard and others: Bull. 522, 1913, 401 pp.
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., 1905, 21 pp.
FENNEMAN, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: Bull. 438, 1911, 73 pp.
*HUMPHREY, R. L., The effects of the San Francisco earthquake and fire on various structures and structural materials: Bull. 324, 1907, pp. 14–61. 50c.
*——— Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo.: Bull. 329, 1908, 85 pp. 20c.
*——— Portland cement mortars and their constituent materials: Results of tests, 1905 to 1907: Bull. 331, 1908, 130 pp. 25c.
*——— The strength of concrete beams; results of tests made at the structural-materials testing laboratories: Bull. 344, 1908, 59 pp. 10c.
*——— The fire-resistive properties of various building materials: Bull. 370, 1909, 99 pp. 30c.
KÜMMEL, H. B., and others, Raritan (N. J.) folio (No. 191), Geol. Atlas U. S. (in press). 25c.
LANDES, H., Cement resources of Washington: Bull. 285, 1906, pp. 377–383. Exhausted. May be seen at many public libraries.
MARTIN, G. C., The Niobrara limestone of northern Colorado as a possible source of Portland cement material: Bull. 380, 1909, pp. 314–326. 40c.
PEPPERBERG, L. J., Cement material near Havre, Mont.: Bull. 380, 1909, pp. 327–336. 40c.
RICHARDSON, G. B., Portland cement materials near El Paso, Tex.: Bull. 340, 1908, pp. 411–414. 30c.
RUSSELL, I. C., The Portland cement industry in Michigan: Twenty-second Ann. Rept., pt. 3, 1902, pp. 620–686. $2.
*SEWELL, J. S., The effects of the San Francisco earthquake on buildings, engineering structures, and structural materials: Bull. 324, 1907, pp. 62–130. 50c.
SHAW, E. W., Gravel and sand in the Pittsburgh district, Pennsylvania: Bull. 430, 1910, pp. 388–399.
SMITH, E. A., The Portland cement materials of central and southern Alabama. Senate Doc. 19, 58th Cong., 1st sess., 1903, pp. 12–23.
——— Cement resources of Alabama: Bull. 225, 1904, pp. 424–447. 35c.
TAFT, J. A., Chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements: Twenty-second Ann. Rept., pt. 3, 1902, pp. 687–742. $2.

SURVEY PUBLICATIONS ON CLAYS, FULLER'S EARTH, ETC.

In addition to the papers named below, some of the publications listed on pages 375–376 and certain of the geologic folios contain references to clays. 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 publications marked "Exhausted" are no longer available for distribution but may be consulted at the larger libraries of the country.

ADAMS, G. I., and HAWORTH, ERASMUS, Economic geology of the Iola quadrangle, Kansas: Bull. 238, 1904, pp. 69–74. 25c.

ALDEN, W. C., Fuller's earth and brick clays near Clinton, Mass.: Bull. 430, 1910, pp. 402–404.

ASHLEY, G. H., Notes on clays and shales in central Pennsylvania: Bull. 285, 1906, pp. 442–444. Exhausted.

ASHLEY, H. E., The colloid matter of clay and its measurement: Bull. 388, 1909, 65 pp.

BASTIN, E. S., Clays of the Penobscot Bay region, Maine: Bull. 285, 1906, pp. 428–431. Exhausted.

BRANNER, J. C., Bibliography of clays and the ceramic arts: Bull. 143, 1896, 114 pp. Exhausted.

——— The clays of Arkansas: Bull. 351, 1908, 247 pp.

BUTTS, CHARLES, Economic geology of the Kittanning and Rural Valley quadrangles, Pennsylvania: Bull. 279, 1906, pp. 162–171. 50c.

——— Clays of the Birmingham district, Alabama: Bull. 315, 1907, pp. 291–295. 50c.

CRIDER, A. F., Clays of Western Kentucky and Tennessee: Bull. 285, 1906, pp. 417–427. Exhausted.

DARTON, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper 65, 1909, 106 pp.

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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 Bullletins 285 and 315, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. Bulletin 315 can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

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PHOSPHATES.

PHOSPHATE DEPOSITS IN SOUTHWESTERN VIRGINIA.

By George W. Stose.

INTRODUCTION.

Commercial phosphate rock is not known to occur in Virginia, the nearest deposits of consequence being those at Columbia, in central Tennessee, where high-grade phosphate is mined on a large scale. The phosphate bed here described is probably not of work-

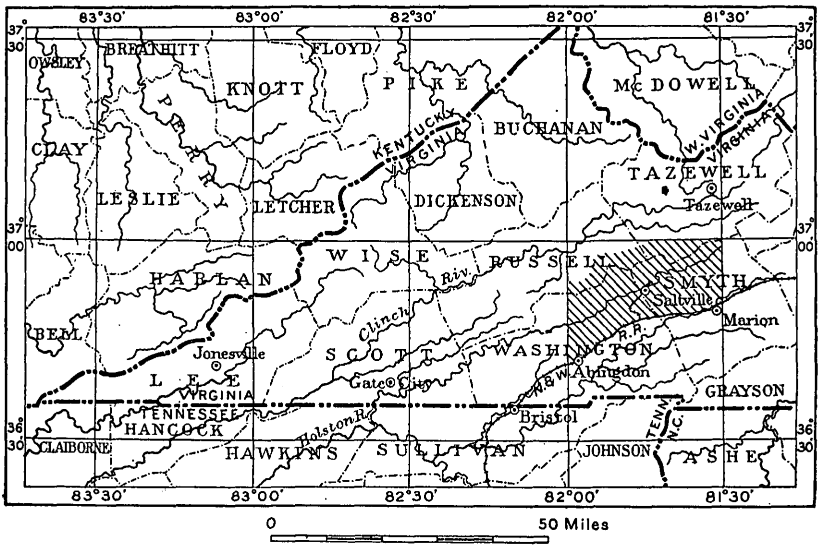

Figure 34.—Map of southwestern Virginia, showing by ruled pattern the area described and mapped in this report. Railroad connections for this area only are shown.

able size and is therefore rather of scientific interest than of practical value, although its discovery may lead to the finding of workable deposits. The location of the area is shown in figure 34.

Phosphate deposits have been observed at two localities in the area mapped by the United States Geological Survey as the Abingdon quadrangle, in southwestern Virginia—at the foot of the southeast slope of Clinch Mountain, 5 miles west of Saltville, and in Walker

Valley at the east end of Brushy Mountain, 5 miles west of Marion. The horizon at which the phosphate occurs has been traced from the Clinch Mountain locality for 20 miles northeast and southwest across the Abingdon quadrangle, and for about 2 miles in the Brushy Mountain locality, as shown on the geologic map, figure 35. It has also been mapped along the east slope of Walker Mountain for about 15 miles in the quadrangle, but the phosphate was not seen there.

TOPOGRAPHY OF THE REGION.

Clinch Mountain is a massive ridge trending northeast and southwest across southwestern Virginia into Tennessee. In the Abingdon quadrangle it comprises several nearly parallel high ridges which accompany an offset in the mountain in this vicinity. Its general altitude in the quadrangle is between 4,000 and 4,500 feet, attaining a maximum of 4,550 feet in Whiterock Mountain.

Walker Mountain, which begins as a low ridge about 8 miles northeast of Abingdon, runs northeastward parallel to Clinch Mountain and in the eastern part of the quadrangle reaches an altitude of 3,800 feet. Brushy Mountain is a local outlying ridge on the southeast side of Walker Mountain having an altitude of 3,500 feet.

The area between Clinch Mountain and Walker Mountain comprises alternate longitudinal valleys and hills. Along the southeast foot of Clinch Mountain is a valley whose soil is so barren that it is called Poor Valley. It is drained by several short streams which cut through Pine Mountain, a high ridge that lies to the southeast, between it and the valley of the North Fork of Holston River. Pine Mountain is a narrow, nearly straight ridge parallel with Clinch Mountain, having an elevation ranging from 2,500 feet to 3,000 feet in the area mapped. As the North Fork of Holston River lies directly at the foot of Pine Mountain and has an altitude of 1,600 feet, its tributaries are short and steep and are actively scouring the adjacent mountain. They have also cut deep ravines and coves in the side of Clinch Mountain. To the east of the Holston Valley lie rounded and irregular hills about 2,000 to 2,500 feet in elevation, which are remnants of a former plain that has been dissected by short transverse branches of the North Fork. Between these hills and Walker Mountain lies a broad, open valley, with fertile limestone soil, called Rich Valley.

Much of this area is either timbered or is cleared for pasture. Rich Valley and portions of the fertile lowlands bordering the North Fork are cultivated. A great number of export cattle are raised on the fertile western slopes of Clinch Mountain and in the adjacent valleys, and some are pastured in the valleys on the eastern slope and on the hills adjacent to the river, although the soil here is poorer and the grass not so luxuriant. The higher parts of the mountains and the rocky portions of the slopes are timbered, mostly with second growth, although a few patches of virgin forest, largely evergreen, still remain in the more inaccessible areas.

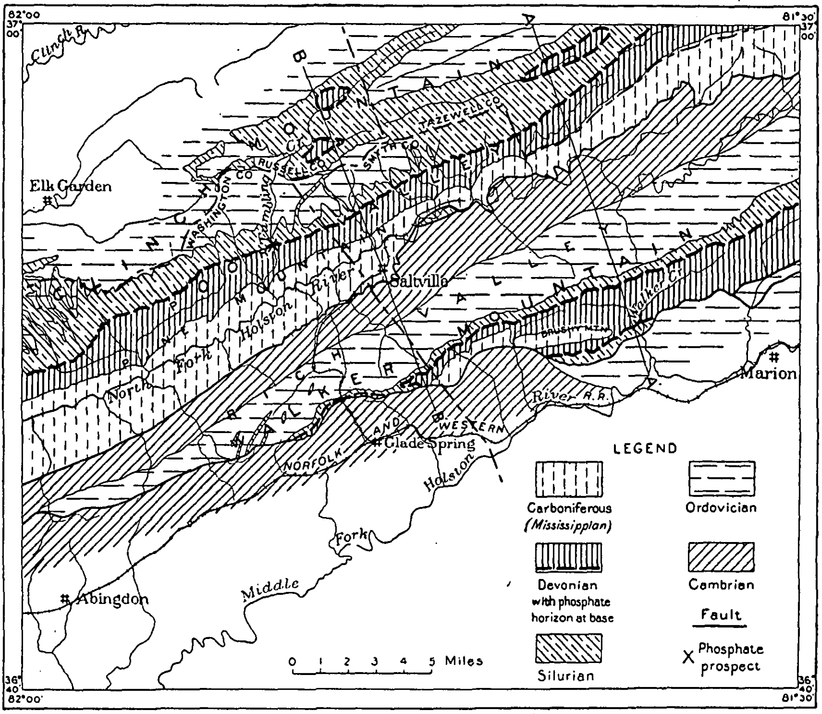

FIGURE 35.—Geologic map of part of the Abingdon quadrangle, Virginia, showing the distribution of the phosphate-bearing rock.

GEOLOGY OF THE REGION.

GENERAL SECTION.

The rocks of the area herein described comprise all the Paleozoic systems from the Cambrian at the base to the Carboniferous at the top, as represented on the geologic map (fig. 35). Those northwest of the great Rome fault, which passes through the area, differ somewhat in lithology, thickness, and faunal content from those on the southeast, so that the section given in the following table is representative of the whole area only in a general way.

Section of rocks in part of the Abingdon quadrangle, Virginia, and correlations with formations of adjacent areas.

System.	Bristol quadrangle, southwest of this area.	Part of Abingdon quadrangle, Virginia. Character.	Thickness.	Pocahontas and Tazewell quadrangles, northeast of this area.
			Feet.	
Carboniferous (Mississippian series).	Newman limestone.	Calcareous gray shale.	400+	Greenbrier limestone.
		Red calcareous crinoidal sandstone. Few fossils of Mississippian age.	70	
		Calcareous bluish-gray shale and laminated earthy limestone.	1,150	
		Massive blue and gray fossiliferous limestone, in part grano-crystalline and containing some chert. Numerous fossils of lower Mississippian age.	250	
	Grainger formation.	Black and red shales, earthy calcareous sandstone, impure limestone, and red clay with gypsum and salt beds. (Maccrady formation.) Large molluscan fauna of lower Mississippian age.	765	Pulaski shale.
		Thin-bedded, irregular-layered coarse white to bluish-gray sandstone. Small fauna, probably of Pocono age.	420	Price sandstone.
Devonian.		Massive reddish and gray arkosic sandstone with scattered quartz pebbles. Chemung fauna.	1,800	Kimberling shale.
		Sandy shale with thin fine-grained sandstones, coarser toward the top. Chemung fauna.		
		Olive colored to gray fissile shale, with interbedded black shale toward the base. Portage (Manticoceras) fauna.	735	Romney shale.
	Chattanooga shale.	Black carbonaceous fissile shale. Characteristic small Genesee fossils.	175	
	Hancock limestone.	Massive light and dark chert layers. Large Oriskany fauna.	125	Giles formation.
Silurian.		Impure finely laminated magnesian limestones; calcareous gray sandstone, weathering porous, at the base. Cayuga ostracodes and other shells.	0–145	
	Rockwood formation.	Soft greenish-gray shale and rusty to red ferruginous sandstone. Numerous Clinton fossils in places.	0–235	Rockwood formation.
	Clinch sandstone.	Pure white quartzose sandstone of upper Medina age.	0–180	Clinch sandstone.
Ordovician.	Bays sandstone.	Coarse, loose-textured red to brown sandstone and shale. Numerous fossils of Maysville age in lower part.	500	Bays sandstone.

Section of rocks in part of the Abingdon quadrangle, Virginia, and correlations with formations of adjacent areas—Continued.

System.	Bristol quadrangle, southwest of this area.	Part of Abingdon quadrangle, Virginia. Character.	Thickness.	Pocahontas and Tazewell quadrangles, northeast of this area.
			Feet.	
Ordovician.	Sevier shale.	Light-gray to buff soft shale containing thin crystalline fossiliferous limestones, with sandstone beds toward the top. Eden fossils in upper part and Trenton fossils in lower part.	800	Sevier shale.
Ordovician.	Moccasin limestone.	Red to greenish-gray finely banded argillaceous limestone, sandstone, and shale.	400	Moccasin limestone.
Ordovician.	[Not present.]	Light-gray granular crystalline and compact dark-blue shaly limestones and calcareous shale. Fossils of uppermost Chazy age.	200	Chickamauga limestone.
Ordovician.	Athens shale.	Platy calcareous shale and dark-blue shaly limestone in upper part; dark-gray fissile shale below. Normanskill graptolite fauna.	500–600	Chickamauga limestone.
Ordovician.	Chickamauga limestone.	Fine-grained to coarse granular light-gray limestone. Numerous fossils of Stones River age.	400	Chickamauga limestone.
Ordovician.	Knox dolomite.	Interbedded impure gray laminated magnesian limestone and blue limestone, with thin sandstones and chert layers. Gastropods of Beekmantown age.	2,371	Knox dolomite.
Cambrian.	Knox dolomite.	Coarse dolomite, generally weathered to red granular soil, some light-gray impure limestone, and chert with cryptozoans.	1,500±	Knox dolomite.
Cambrian.	Nolichucky shale.	Interbedded finely banded limestone and dark-gray shale. Trilobites and other fossils of Upper Cambrian age.	400–580	Nolichucky shale.
Cambrian.	Honaker limestone.	Coarse gray dolomite, thin-bedded fine-grained dolomite, and dolomite conglomerate, with round banded cherts. Closely resembles dolomite of Elbrook formation of northern areas.	600±	Honaker limestone.
Cambrian.	Russell formation.	Red shale and rusty-gray sandstone, with large rough cherts at the top. Equivalent to Watauga shale southwest of the area.	460	Russell formation.

CAMBRIAN SYSTEM.

Cambrian rocks are exposed in this area only southeast of the Rome fault. They are chiefly dolomite and limestone, with subordinate amounts of shale and sandstone. They comprise formations which have been described and mapped in adjacent areas as the Russell formation (lowest), Honaker limestone, Nolichucky shale, and the lower part of the Knox dolomite. Only the red shales, sandstones, and large rough cherts of the upper part of the Russell formation are known to be exposed in the area here described. To the southwest these beds have been called the Watauga shale. The Honaker limestone and Nolichucky shale are not readily distinguishable as separate formations in many parts of the area, but in general comprise a lower series of about 600 feet of coarse dolomite and thin-bedded finer-grained dolomite, with round banded cherts and dolomite conglomerate at the base, closely resembling the dolomite of the Elbrook formation of northern areas, and an upper series of about 500 feet of interbedded finely banded dark-blue limestone and shale. The shale decreases toward the east and is probably entirely absent at the east edge of the quadrangle, but even there the Nolichucky can generally be recognized by the marked finely siliceous banded character of some of the limestone beds and the flat-pebble "edgewise" limestone conglomerates.

The lower part of the Knox is largely a coarse dolomite which weathers to a deep-red granular soil but contains many harder light gray to blue impure limestone beds and cryptozoan-bearing cherts with wavy banding.

ORDOVICIAN SYSTEM.

The Ordovician rocks are largely limestones in the lower part and shales and sandstones above and form valleys and the slopes of mountains. The valleys, of which Rich Valley is the most important, are generally fertile. As described in reports on adjacent areas, these rocks comprise the upper part of the Knox dolomite and the Chickamauga limestone, Athens shale, Moccasin limestone, Sevier shale, and Bays sandstone, Only the Sevier and Bays formations occur northwest of the Rome fault in the area here described.

The upper part of the Knox is a thick series of interbedded hard, finely laminated light-gray impure magnesian limestone and purer blue limestones, with thin calcareous sandstones and massive white chert layers. It can generally be recognized by its rather meager fauna, chiefly gastropods, which indicate Beekmantown age. The Chickamauga limestone is largely a pure light-gray fine to coarse-grained limestone, about 400 feet thick, and is the best rock in the region for lime burning. Its fossils are of Stones River age. The lower part of the Athens shale is a dark-gray fissile shale, with thin limestone beds, containing a graptolite fauna, correlated by Ulrich with the Normanskill shale. Above these beds are dark-blue shaly limestones and calcareous shale with a meager graptolite fauna.

Overlying the Athens shale are dark-blue shaly and light-gray granular crystalline limestones containing numerous fossils, correlated by Ulrich with the uppermost part of the Chazy, which is called by him the Ottosee limestone. These beds are apparently not present to the southwest in the Bristol area. The beds at this horizon, together with the Athens shale, which becomes increasingly calcareous toward the northeast, have heretofore been included with the Chickamauga limestone in the Tazewell and Pocahontas quadrangles. The overlying Moccasin limestone is made up of finely banded argillaceous limestone, fine-grained marble, sandstone, and shale, is usually red and greenish in color, and contains few fossils. It is about 400 feet thick. The Sevier shale, a thick, soft light greenish-gray to buff shale, has thin-bedded limestones in the lower part and sandy beds and sandstones toward the top. The fossils of the limestones are correlated by Ulrich with the Trenton and those of the upper beds with the Eden, so that the formation closely resembles the Martinsburg shale of northern areas. The sandy beds grade into the Bays sandstone, a formation of coarse, loose-textured red to brown sandstone and red shale. Its lower portion contains numerous fossils of Maysville age, and the overlying apparently barren red beds may represent the Juniata or lower part of the Medina. As the Bays sandstone directly underlies the hard Clinch sandstone, it occurs chiefly in the upper slopes of the sandstone ridges.

SILURIAN SYSTEM.

The Silurian rocks are largely sandstones and sandy shales included in the formations previously mapped as Clinch sandstone and Rockwood formation. The Clinch, the mountain-making formation of the region, is a pure white quartzose sandstone or quartzite, about 200 feet thick in Clinch Mountain, where some of its massive layers are 25 feet thick. In Walker Mountain, on the southeast, it has a maximum thickness of 90 feet and thins out toward the southwest. No fossils were found in it except the supposed plant *Arthophycus harlani*, which in places covers large surfaces of the white rock. Above the sandstone are soft greenish-gray shale and red ferruginous sandstone, about 235 feet thick, which contain a typical Clinton fauna. Overlying these rocks are about 150 feet of sandy magnesian limestones and porous calcareous sandstones, which contain small ostracode and other shells characteristic of the Cayuga formation of the northern Appalachians. These two softer formations are not known to be exposed southeast of the Rome fault and are probably not present on the southeast slope of Walker Mountain.

DEVONIAN SYSTEM.

The Devonian rocks are largely shales and sandstones, but the lowest formation of this age is a massive chert. The sandstones form a high straight ridge named Pine Mountain and the shales the barren valley called Poor Valley. These strata, in the region to the north, have been described in ascending order as the Giles formation, Romney shale, and Kimberling shale and in the region to the south as the Hancock limestone, Chattanooga shale, and Grainger formation. The massive chert, 125 feet thick west of the fault, in part represents the Hancock limestone of the Bristol area and the Giles formation of the northern area, these formations apparently including also the underlying limestones of Cayugan age. The chert is generally very fossiliferous at the base, where it contains a well-recognized Oriskany fauna. Directly overlying the chert is a black coaly shale followed by fissile black shale, the whole 175 feet thick west of the fault, correlated by some geologists with the Chattanooga shale. It was found to contain a characteristic Genesee fauna and has the lithologic character and stratigraphic position of the Genesee shale. The black shale grades upward by gradual transition into olive-colored and gray fissile shale having a thickness of over 700 feet and containing a fine development of the Manticoceras fauna of the Portage formation. Beautifully preserved coiled cephalopods, 2 to 3 inches in diameter were collected from this shale. It is followed by sandy shales with thin beds of fine-grained sandstone, which becomes coarser and more abundant higher in the section. The fossiliferous coarser beds yield a characteristic Chemung fauna. The Devonian culminates in heavy, irregularly bedded, somewhat arkosic reddish sandstones, which also contain a meager Chemung fauna and probably represent a phase similar to the Catskill formation of New York. The strata of Chemung age are about 1,800 feet thick.

CARBONIFEROUS SYSTEM.

The Carboniferous strata exposed in the area include sandstone and shale in the lower part and limestone above. They comprise the Price sandstone, Maccrady ("Pulaski") formation, and Newman limestone of published reports. The Price sandstone, 400 feet thick, caps a high wooded mountain ridge and the limestone and shale form low rounded hills and valleys, which are generally cleared and used as pasture for cattle. In the upper layers of the Price sandstone are thin coal seams which increase in size, thickness, and range northeast of the area. Fossil shells at its base are of Mississippian age.

The Price is overlain by about 750 feet of dark shale, soft earthy sandstone, and thin impure limestone, which locally contain gypsiferous and saline clays that are of commercial value at several places along the great Rome fault. This formation is called the Maccrady. It contains numerous fossil shells and plants of Mississippian age, which find their closest ally, according to G. H. Girty, in the Moorefield shale of Arkansas. The Maccrady is followed by massive, highly fossiliferous limestones which grade upward into argillaceous or earthy limestones that weather to shales, the whole constituting the Newman limestone. The fauna is reported by Girty to be closely related to that of the Batesville sandstone of Arkansas. Near the top of the Newman limestone as exposed in the area is a red calcareous crinoidal sandstone. The exposed thickness of the Newman is 1,600 feet. The Pennington shale, also of Mississippian age, which overlies the Newman limestone in adjacent regions, is not present in this area.

STRUCTURE AND DISTRIBUTION OF THE FORMATIONS.

Southwestern Virginia lies within the closely folded belt of the Appalachian Mountains. The rocks occur in great elongated folds with axes trending northeast and southwest, their length being measurable in miles, some in hundreds of miles, and their height in hundreds and even thousands of feet. They are cut here and there by great longitudinal breaks or faults along which the strata have been displaced. (See fig. 36.)

The rocks were once sediments of various kinds deposited nearly horizontally in the sea and later consolidated, and the beds attained their present attitude by being compressed by powerful earth forces that bent the strata into great elongated folds at right angles to the direction of compression. The axial planes of the folds generally dip southeast, indicating that the compressive force near the surface acted from that direction. The faults also show this same direction

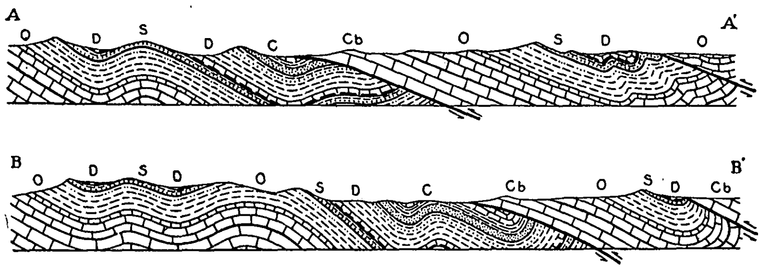

FIGURE 36.—Structure sections along lines A–A′ and B–B′, figure 35, showing the probable extent underground and relation of the phosphate-bearing rock. Cb, Cambrian rocks; O, Ordovician rocks; S, Silurian rocks; D, Devonian rocks; C, Carboniferous rocks. Horizon of the phosphate-bearing rock shown by heavy dashes. Scale, twice the scale of the map (fig. 35).

of movement, the rocks on the southeast of nearly every fault having been pushed or thrust over those on the northwest, in some places several thousand feet. Most of the faults originated in folds that were compressed to a degree beyond the shearing strength of the rocks, which thereupon yielded by fracture and by sliding along the fracture or fault plane.

Two such great faults cross the area here described. The larger one, called the Rome fault because it is continuous with the fault at Rome, Ga., passes through Plasterco, Saltville, Maccrady, and Broad Ford. On the northwest side of the fault is a compressed syncline of Carboniferous limestone and shale, whose axis pitches southwestward, and the syncline correspondingly deepens in that direction. Toward the northeast the Carboniferous rocks along the fault are partly hidden beneath the overthrust mass. Following the Carboniferous limestone and shale in monoclinal sequence northwestward are the basal Carboniferous sandstone and Devonian sandstone forming Pine Ridge, the Devonian interbedded shales and thin sandstones and chert underlying Poor Valley, the Silurian shales and sandstones forming the east slope and crest of Clinch Mountain, and the softer Ordovician rocks occupying most of the western slope of Clinch Mountain and coves on the eastern slope. Near the north edge of the area an anticline plunging northeastward causes the mountain-making Clinch sandstone and associated rocks to swing back, producing the offset of the mountain previously mentioned and a corresponding multiplication of ridges.

Directly adjacent to the Rome fault on the southeast are the lowest Cambrian strata exposed in the area. They are followed southeastward by successively higher strata through the Cambrian and Ordovician to the Clinch sandstone of the Silurian, forming Walker Mountain, and the Devonian shales in the valley on the southeast. Carboniferous sandstones, the highest rocks locally preserved in this syncline, form Brushy Mountain.

The second great fault, called the Walker Mountain fault, follows an irregular line at the east foot of Brushy Mountain and to the southwest cuts diagonally across the rocks of Walker Mountain until the mountain-making beds are cut off and the mountain terminates. Cambrian and Ordovician rocks form the front of the overthrust mass southeast of the fault. In the vicinity of Brushy Mountain some Silurian and basal Devonian beds are infolded next to the fault and are of special economic importance because of their content of phosphate.

PHOSPHATE ROCK.

OCCURRENCE.

The phosphate rock occurs at the base of strata of known Oriskany age and is probably basal Devonian. It has thus far been observed at only two places in the Abingdon quadrangle, but the horizon at which it occurs has been traced across the area, and its several bands are shown on the map. Careful search along these lines of outcrop will no doubt reveal the presence of the phosphate rock at many other places, although it seems to be represented by red ferruginous sandstone in certain sections.

TUMBLING CREEK.

One of the tributaries of North Fork of Holston River descends the steep southeastern slope of Clinch Mountain in Tumbling Creek and has bared the lower Devonian and upper Silurian rocks so that they are now exposed in the floor and cliffs of the narrow gorge at Henderson's mill. At no other place in the area were these rocks so well displayed for examination. Generally the slopes of the mountain are mantled by sandstone débris from above, and the chert formation is visible only in small scattered outcrops or is represented merely by loose fragments of chert, although better outcrops may be seen in some stream gorges. The general absence of good exposures of the soft rocks beneath the chert accounts for the lack of recognition of the phosphate bed at other points along the foot of Clinch Mountain.

The following detailed section was measured at Henderson's mill on Tumbling Creek:

Detailed section of the rocks containing the phosphate bed at Tumbling Creek, 5 miles west of Saltville.

	Feet.
Massive beds, 1 to 3 feet thick, of hard black and white flint and chert-bearing limestone, with numerous characteristic Oriskany fossils	24
Fine greenish conglomerate of small, rounded white quartz pebbles and limestone pebbles cemented by white calcite, and containing grains and large nodules of dark phosphate. About.	1
Gray and reddish, finely laminated, porous, calcareous sandstone, greenish toward the top, with trace of calcium phosphate	14
Concretionary calcareous sandstone with shaly limestone, and wavy banding at the base	2
Thinly laminated drab limestone, weathering light gray, containing characteristic Cayuga Leperditia	12

Although the bed containing the phosphate nodules and grains in sufficient quantity to be called phosphate rock is a little less than a foot thick in this section, the sandstones just beneath seem also to contain a small amount of phosphate. From the nature of the deposit it probably varies in thickness more or less, and in the concealed portion it may be slightly thicker or thinner than where measured.

WALKER CREEK.

The other observed occurrence of phosphate rock is on Walker Creek at the east end of Brushy Mountain, 5 miles west of Marion, where the following section is exposed in the new roadway recently cut in the hillside west of the stream:

Detailed section on Walker Creek.

	Feet.
Nodular black flint with shaly partings. Contains characteristic Oriskany fossils	40
Fine rounded grains of shiny dark green glauconite, with phosphatic matrix, and nodules and layers of dense fine-grained phosphate rock	1⅓
Largely covered. Sandy limestone and chert with Oriskany fossils at the top	15
Thin-bedded light-green sandstone	15

Here also the concentrated phosphate rock is only a little over 1 foot thick, but the underlying sandstone is apparently also more or less phosphatic.

EXTENT.

As previously stated, although the phosphate bed has been observed at only two places, it probably has considerable extent along the outcrop of the beds at its horizon, shown on the map by the heavy dashed line. These beds lie along the southeast slope of Clinch Mountain between Devonian chert above and Silurian sandstone and shales below. From Tumbling Creek they follow the foot of Redrock Mountain and Flattop Mountain to the vicinity of Tannersville, where they swing back around the end of Flattop Mountain into Little Valley and then on northeast again, following the southeast foot of the offset Clinch Mountain. Two outliers of the horizon occur on the mountain top around Brier Cove and Laurel Bed.

Another line of outcrop of these beds was traced along the southeast side of Walker Mountain from a point near Emory northeastward as far as the edge of the area shown in figure 35. In this belt, however, the phosphate rock was not observed, although careful search will probably reveal its presence in places.

The belt along the outcrop of phosphate rock on Walker Creek is of small extent, perhaps 2 or 3 miles in length, as it is cut off in both directions by the Walker Mountain fault.

The extent of the phosphate rock underground can be only surmised, but as it is found at two points widely separated across the strike of the beds, it is probably more or less continuous underground between them. The rocks dip about 25° SE. along Clinch Mountain and the phosphate-bearing bed therefore descends in this direction at 25° from the horizontal for an indefinite distance and is eventually cut off by the Rome fault. About the same dip prevails on the east side of Walker Mountain, where the rocks at the phosphate horizon descend southeastward in the same way. At Walker Creek the dip is 55° SE., but as the chert is on the west and the sandstone on the east, the relations are inverted and the dips are overturned, as shown at the right in section A–A′, figure 36. The beds containing the phosphate therefore descend at 55° from the horizontal toward the southeast for a short distance, then steepen, and at no great depth turn back at the bottom of the syncline and connect with the Walker Mountain outcrop of these beds.

APPEARANCE AND CHEMICAL COMPOSITION.

The phosphate rock collected in this area is of four types. One, a conglomerate of white quartz pebbles a quarter of an inch in diameter and larger light-colored limestone pebbles, with black calcium phosphate nodules of similar size, in a dark greenish-gray phosphatic matrix, occurs at Tumbling Creek. The exposed surface of the rock is coated by the characteristic faint bluish-white film of calcium phosphate. Analysis of a phosphate nodule from this rock showed

16.72 per cent of P_2O_5, equivalent to 36.5 per cent of tricalcium phosphate.

Another type that occurs at Tumbling Creek is a granular sandstone of rounded quartz grains with calcareous and phosphatic cement containing scattered grains and larger nodules of calcium phosphate. The rock has a greenish color that is due apparently to the disseminated phosphate, and on weathering it becomes coated with the characteristic milk-white film. Analysis of the granular rock without phosphate nodules showed only 0.22 per cent of P_2O_5; 34 per cent was $CaCO_3$ and the rest largely insoluble silica.

The phosphatic glauconite rock from the Walker Creek area is composed of fine shiny grains of greenish-black glauconite in a light-gray phosphatic cement. The glauconite weathers rusty brown, which gives the weathered rock a mottled rusty color. Analysis of the glauconitic rock with little visible phosphatic matrix gave 1.17 per cent P_2O_5.

The phosphatic glauconite rock of Walker Creek grades into a very compact fine-grained gray phosphate by the gradual diminution of the glauconite grains and increase of the phosphatic matrix. It weathers at the surface to a thick white coating, which also forms along the smooth joint planes that cut through it. This is the richest phosphate rock collected, and its analysis shows 25.17 per cent of P_2O_5, equivalent to 54.97 per cent of tricalcium phosphate.

AGE AND ORIGIN.

The phosphate bed, as previously stated, occurs below chert containing Oriskany fossils and above rocks containing Cayuga fossils, the limestone of Helderberg age apparently being entirely absent. The phosphate bed, composed of grains and small pebbles of quartz, glauconite, and phosphate nodules, probably represents the beginning of Oriskany sedimentation after an interval of land conditions during Helderberg time.

The area was probably but slightly raised above the sea during this brief interval, so that erosion did not carry away the products of disintegration of the recently deposited sandy limestone of Cayugan age. As the lime was dissolved it left a regolith of quartz sand with scattered quartz pebbles, rounded fragments of partly dissolved impure limestone, and probably innumerable small shells of ostracodes which crowded the limestone. On the reinvasion by the sea glauconite grains were formed, possibly by the action of decomposing animal matter upon the iron and other minerals in the sea water, and phosphate nodules were formed by the concentration around organic centers of calcium phosphate probably dissolved, from numerous phosphatic shells, possibly ostracodes. These were intermixed with the siliceous sediment to form the basal deposit of the Oriskany epoch.

During the rest of Oriskany time the land conditions were such that detrital material was not carried into this part of the sea, the deposits consisting of fine calcareous and siliceous ooze in which calcareous shells of mollusks and other marine animals that lived in the sea were buried. Later this ooze hardened to massive chert, and the fossil shells were also altered to silica.

TRANSPORTATION AND MARKET.

Although the deposits of phosphate here described are probably not of commercial value, those on Walker Creek are most favorably located for transportation, being but 3 miles by road down a gentle grade through an open country to the main line of the Norfolk & Western Railway, and but 5 miles from Marion. If deposits are found along the southeast slope of Walker Mountain at the horizon indicated, they will be almost as advantageously located, the railroad paralleling the mountain at a distance of about 4 miles. The Clinch Mountain locality is less accessible. The Tumbling Creek exposure is about 4 miles in an air line from the Saltville branch of the Norfolk & Western Railway, but the construction of a contemplated branch railroad up Poor Valley, which has already been surveyed, would make the east foot of Clinch Mountain readily accessible.

USES AND TREATMENT OF PHOSPHATE ROCK.

Phosphate rock is the most important source of phosphorus, which is one of the three necessary elements of plant food in all soils, the others being nitrogen and potash. Many soils that contain relatively large amounts of nitrogen and potash, but are deficient in phosphorus, are greatly benefited by the application of phosphate rock alone. The usual method of preparing phosphate rock for use as fertilizer is to dissolve it in an equal weight of sulphuric acid, a treatment that makes the phosphorus immediately available for the use of plants. The product is called superphosphate. Raw phosphate rock, either finely ground or roasted and ground, is used successfully on the heavier humus-bearing soils without further treatment or in combination with barnyard manure. If raw ground phosphate is applied to land, the phosphorus thus added to the soil is liberated for the use of the plant more gradually than if superphosphate is applied, but the amount of phosphorus eventually supplied to the soil from a ton of the raw phosphate is about double the amount supplied from a ton of superphosphate and the effects are said to be more lasting, though not so intense.

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SALINES.

NOTES ON THE QUATERNARY LAKES OF THE GREAT BASIN, WITH SPECIAL REFERENCE TO THE DEPOSITION OF POTASH AND OTHER SALINES.

By Hoyt S. Gale.

INTRODUCTION.

The existence of extensive lakes in certain of the larger catchment areas of the Great Basin region undoubtedly had an important influence on the concentration there of saline material. From a study of the physiographic history of the region it appears that some of these catchment basins may now be considered as more favorable and some as less favorable places in which to look for large concentrated saline deposits, especially with reference to the possible occurrence of valuable potash salts. The purpose of the present paper is to suggest a distinction that may be drawn between the desert-basin areas—in effect, a certain classification on the basis of their interpreted history, from which some conclusions of practical importance with reference to saline deposits may be deduced.

LAKE HISTORY OF THE DESERT BASINS.

It is well known that certain large lakes whose waters have now receded or entirely disappeared formerly existed in the Great Basin region. The most clearly recognized of these lakes are supposed to have been coincident with the general extension of glaciation in the higher adjoining mountain ranges, so that they are referred to the glacial epoch of the Quaternary period. Geologic study of the Great Basin has led generally to the conclusion that not only during Quaternary time but throughout several epochs in the Tertiary history of this province there has been aridity of climate and possibly desert basins without exterior drainage. Thus there may have existed at various times large interior lakes which might have left a record of lacustral sediments and chemical deposits resulting from their desiccation. Such records are indeed referred to in the literature on this region as showing lake history of epochs preceding the

Quaternary. The determination whether the Tertiary lakes were simply reservoirs for the accumulation of water that eventually found an outlet into the sea or whether they dried up after long periods of concentration of salines in their waters involves problems of great complexity. The changes in the earth's surface during the Tertiary and Quaternary periods have been so extensive that it seems as if the search for possible final concentration areas of those ancient lakes must be a random enterprise, with little evidence to guide it except the accidental discovery of the salts themselves. For these reasons in the present investigations attention has been directed primarily to the deposits of comparatively recent origin, in which the geologic record is exceptionally complete.

QUATERNARY LAKES OF THE GREAT BASIN.

A classification of the desert basins based on their lake history is suggested in the following descriptions of the major and minor Quaternary lakes that have been recognized in that region. A third member of that classification would include those basins in which, for reasons to be explained, it seems probable that no such lakes have existed.

The monographic studies of Gilbert and Russell on the Quaternary Lakes Bonneville, Lahontan, and Mono have reviewed in detail the evidence by which the existence of these former extensive water bodies has been established. For the discussion of lacustral deposits, shore phenomena, and similar details reference should be made to these reports. Besides the three lakes mentioned others assumed to be of approximately the same period have been recognized, as in the Owens basin, the former Searles Lake, and a deep lake that occupied the Panamint Valley. Although the three last mentioned have received less study, their former existence is considered to be just as firmly established as that of Lakes Bonneville and Lahontan. The shore lines of the ancient lakes at their more persistent levels are still distinctly preserved, and from these and other evidences the history of the lakes has been interpreted.

Still other prehistoric lakes supposed to be of Quaternary age have been recognized elsewhere in the desert basins. For several reasons these have not been classed with the major lakes above enumerated. These include the former lakes in Railroad Valley and at Columbus Marsh, Nev.; those of southern Oregon; and Lake Le Conte, a former body of water occupying the basin of the Imperial Valley or Salton Sink in southern California. Doubtless there are others, as similar lakes have been reported in New Mexico and Texas. Except Lake Le Conte, which may have had a history somewhat different from the others, these minor lakes of the Great Basin are supposed to have had much the same sedimentary and chemical record as the major lakes that have been named, on a scale proportionate to the size and duration of their water bodies.

A belief has gained rather wide acceptance that Quaternary lakes contemporaneous with Bonneville and Lahontan were generally distributed throughout the Great Basin. Gilbert states that vestiges of similar lakes had been found by various observers in many of the valleys of the Great Basin and expresses the belief that all the minor basins of which that area is composed had been partly or wholly filled with water.[1] This idea seems to have generally prevailed to the present day. It was with some surprise, therefore, that in traveling from one of these desert basins to another the present author noted differences in the physiographic records which were not at first clearly understood. Even if lakes once existed in all the desert basins alike, certainly the traces they left, such as ancient shore lines and tufa deposits, are now markedly different even in adjacent valleys. After further observation the author reached the conclusion that few even of the larger basins have in reality contained extensive lakes of Quaternary age. It will be seen that the demonstration of this conclusion as a fact must have an important bearing on the probability of finding valuable saline deposits in the desert-basin region generally.

As noted above, undisputed evidence of a former lake period is found in a few of the desert basins. Conversely, recent observations in the field have seemed to indicate that no traces of such a former lake period are to be found in most of the inclosed drainage areas of the desert basins. Furthermore, the enumeration of the known lake areas makes it evident that mere size of catchment area is not the criterion which determined the existence of a Quaternary lake in a given basin. This should be made clear by the following illustrations:

Death Valley is the "sink" or final point of accumulation for the waters of Amargosa River, which with its tributaries constitutes one of the large independent drainage systems of the Great Basin. Mohave River, which may be considered a tributary of Death Valley or Amargosa River, now empties its flood waters into Soda Lake, an ephemeral body of water, which if it had ever filled its shallow basin to overflow the low divide to the north would have joined the Amargosa. In spite of the immense drainage territory tributary to Death Valley there is no evidence that the waters from these streams ever accumulated in it to a sufficient extent to form more than a shallow inconstant lake. A search for traces of any upper shore lines around the slopes leading into Death Valley has failed to reveal evidence that any considerable lake has ever existed there.

[1] Gilbert, G. K., The glacial epoch: U. S. Geol. Surveys W. 100th Mer., vol. 3, 1875, p. 103.

The Panamint Valley, just across the Panamint Range west of Death Valley, shows a marked contrast in its lake history. In other respects, including general climatic conditions, the Panamint is at first sight wholly comparable to Death Valley. Its lowest part lies at an elevation of 1,050 feet above the sea and it was submerged to a depth of 1,200 feet or more. Thus the water in Panamint Valley stood at a height of some 2,300 feet above the supposedly dry floor of Death Valley. Certainly no generally effective climatic change can alone account for such distinctions.

A similar contrast is afforded by Dixie Valley, which lies east of the former shores of Lake Lahontan, just across the narrow and steep intervening divide of the Stillwater Range. Dixie Valley had no connection with Lake Lahontan, although its bottom now lies 400 feet lower than the lowest part of the Carson Desert. In spite of this difference in elevation and the fact that Dixie Valley is the lowest part of an extensive drainage area, there is no evidence to show that a large or deep lake ever existed in Dixie Valley, and it is believed that no such lake was ever formed.

Other examples may be cited, the contrasts noted demanding an explanation as to why certain drainage areas accumulated lakes in their lowest depressions while other similar and immediately adjacent areas did not. The fact that a simple and adequate explanation may be offered serves to substantiate the original conclusion that was reached from negative field evidence, namely, that most of the minor bolsons[1] in the Great Basin have not contained lakes of any considerable size in the Quaternary period.

If the areas of the major Quaternary lakes and the outlines of their drainage basins are indicated on a sufficiently complete map, it will be noted that all the major lakes have been fed by streams that are even now perennial. These tributaries are the streams which derive their waters directly from the higher summits of the Sierra in Nevada and California, and of the Wasatch Mountains in Utah. Thus the basin of former Lake Bonneville is fed by Bear River and numerous smaller perennial streams. The basin of former Lake Lahontan receives the water of Carson, Truckee, and Walker rivers. Mono Lake lies high in the Sierra and is also fed by perennial waters. Owens River supplies Owens Lake, and here is to be found an explanation of the formation of the ancient Searles and Panamint lakes by overflow from the shallow Owens Basin. Considered by itself Owens Valley would not have been classed with the major Quaternary lake basins. Its abundant water supply was passed on to other reservoirs.

[1] Bolson (Spanish bolsón, large purse) is a term used to designate a constructional detritus plain occupying a structural trough in an arid region. It is therefore a convenient name for the flat valley floor of a desert basin.

A slight increase in the humidity of the climate might easily account for increased flow in all these perennial streams, whose waters rose to correspondingly higher levels than those of the Carson, Pyramid, Winnemucca, Mono, Owens, and Great Salt lakes of to-day. That the increase of humidity may have been but slight is determined by other considerations. The water by which these lakes were filled was probably derived mainly from the snow-capped summits of only the highest mountain ranges on the extreme borders of the Great Basin area.

On the other hand, it is necessary to consider those drainage basins which include only the desert plains or bolsons, and the desert mountain ranges—even the more lofty mountains of the interior Great Basin region. To-day these basins are fed by intermittent streams which are incompetent to flood the lowest bottoms. By analogy with the climate of the present day, a slight increase of humidity of climate probably did not greatly alter the character of this typically desert-basin drainage. Desert conditions, possibly with slight modifications, such as greater frequency of periodic storms, may logically be assumed never to have suffered the establishment of a full, continuous flow in the typically desert-basin drainage areas. This is believed to be true of such streams as Mohave and Amargosa rivers and of many lesser drainage systems. Therefore, the periodic lakes of the typical desert basins probably never filled their basins deeply or for long periods.

Evidence bearing on the slightness of the climatic change required to produce the major lakes of the Great Basin has already been reviewed by Gilbert and Russell. In brief, the failure of Lakes Lahontan and Mono to overflow is believed to have an important bearing. Lake Lahontan is known to have risen to a height of 500 feet over the extensive areas of the Carson and Blackrock deserts. Although a rise of 200 feet more would have established an outlet northward into Columbia River, the balance between evaporation and inflow was maintained below the overflow point. Mono Lake in former high levels approached a point of overflow at 670 feet above its present level, but Russell states that it did not overflow. Increased precipitation in a single year is known to cause a rise of several feet in such a lake as Owens at the present time. A continued slight increase in the same degree might cause a great expansion of this lake without marked difference in climatic conditions.

SALINE DEPOSITION IN THE DESERT BASINS.

The origin of saline deposits in the desert basins is readily explained. By definition these basin areas are independent drainage systems, without external outlet, so that their surface waters flow toward an interior depression or lower part. The Great Basin is made up of many such independent basins.

It is a recognized fact that all natural drainage waters collect and carry onward the soluble constituents of the soils and rocks over which they pass. These constituents become soluble by the process of weathering, a slow but ever-acting surface decomposition, in which the more complex mineral combinations break down to simpler forms, some of which are soluble in water. These soluble constituents find their way toward the lowest part of each of these drainage systems, are accumulated there, and by ultimate evaporation of their solutions are deposited in saline residues. The lowest part of each basin thus becomes an area of concentration for the soluble constituents of its drainage waters as well as an area of accumulation for the sediment washed in by its flood waters. These areas of concentration are variously termed playas, dry lakes, mud flats, and salt marshes if they are usually dry, and saline or "alkaline" lakes if they remain flooded, Most of these areas are now essentially dry. At times of exceptional precipitation these playas are wholly or partly covered by water and fine sediment in suspension is carried out over them. Sand and dust swept across in the more or less frequent wind storms settle and become mixed with the deposits. With the evaporation of the water the dissolved salts are deposited as a saline crust.

Salts and sediments laid down in the beds of periodic lakes of the type described have accumulated in immense deposits. Generally, however, the deposits are much intermingled, consisting of an alternating succession of clay, sand, and salt layers. The muds, as soon as they settle, are quite impervious to the further circulation of the water and form an effective seal against the re-solution of much of the salts once deposited. Thus the deposits of such a lake contain thin salt crusts intercalated between mud strata, and only a small part of the salt is continuously redissolved and so carried on up to the surface of each succeeding deposit. For this reason lakes of relatively dilute water may stand for long periods over deposits of playa muds carrying large quantities of crystalline salt.

Each temporary flooding deposits but a thin crust of salts upon its evaporation. A lake of larger size and longer duration may accumulate a correspondingly greater quantity of salts. While these salts remain in solution sediment which is washed into the lake settles and thus the salts are concentrated in the water and separated from the sediment. If such a lake persists for a long time it may accumulate a vast quantity of dissolved salts and if it ultimately dries up may deposit these salts in a single massive crystalline layer. An excellent example of a deposit formed in this way is that at Searles Lake, in California.

From the foregoing discussion it is evident that saline residues in massive crystalline deposits are to be naturally expected only as the result of the final evaporation of an extensive and deep saline lake, one which represents the continuous accumulation of the dissolved salts during a very long period of time. As the former existence of such lakes has been demonstrated in only a few of the desert-basin areas, it appears evident that salt deposits of this type are to be expected in only a few localities.

Potash is one of the normal constituents of most natural saline deposits. The common soluble salts of such deposits in the Great Basin are the chlorides, sulphates, carbonates, bicarbonates, and borates of sodium and potassium. Magnesia and lime are present as very minor constituents. In nearly all the deposits the sodium salts very greatly predominate. In the average of a large number of representative American river waters the ratio of potash to soda in the dissolved salts is as 1 to a little more than 4—that is, potash is about one-fifth of the total alkalies (soda and potash together). In the waters of saline lakes in the Great Basin region the ratio of potash to soda is perhaps even smaller. Analyses of saline residues in the Great Basin commonly show from 1 to 4 or 5 per cent of potash in the soluble constituents.

Potash salts in a solution containing other salts will be deposited with the rest when that solution is evaporated. If in such a solution potash is present in very much smaller quantity than soda, it is naturally to be expected that during the evaporation of the solution the potash will reach saturation later than the soda. Therefore the potash salts of such an evaporating solution have a tendency to remain in the residual brines while a portion of the sodium is crystallized out. The potash is thus partly segregated in the brine or "mother liquor" of the crystallizing salt body. Such segregation can take place on a large scale only when it acts in a single massive deposit of crystallizing salts. In this fact lies a further reason why important segregation of potash should be expected only as the result of the final evaporation of an extensive and deep saline lake, representing the continuous accumulation of dissolved salts during a very long period of time. Again the reasoning points to the elimination from practical consideration, as a favorable site for the occurrence of potash, of most playa deposits, dry lakes, mud flats, or salt marshes, unless it can be shown that the basins in which they lie have at some time contained large lakes.

The only important example now known of a massive deposit of salines resulting from the evaporation of a Quaternary lake is that at Searles Lake, Cal. Here the salts lie at the surface of the ground and the natural situation of the deposit has prevented its becoming covered and concealed by later inwash of sediment. Such saline deposits may also exist in the low parts of other Quaternary lake basins, where they have become covered and concealed by sediments. It was on the theory that such a deposit might be discovered near the center of Carson Sink, Nev., that a well was sunk there to a depth of 985 feet by the Geological Survey. The first trial has failed to locate the saline deposits sought and it may be that the estimate as to the site of a former area of concentration was not correct. It is also possible that the well did not go deep enough, but these are matters that deserve further discussion.

CONCLUSIONS.

As a result of the considerations that have been presented, it is believed that most of the saline crusts, dry-lake areas, salt flats, "sinks," or playas in the desert-basin region offer little promise for the development of commercial sources of potash salts. Potash locations are still being reported from many parts of the desert-basin country, and it is thought that in many, perhaps in most cases, the cost of staking these claims and other expenses involved in such work are incurred without a distinct understanding of the natural limitations implied in the theory of saline deposits from desiccated lakes. Most playa muds contain soluble salts, some of them in considerable quantity. These salts when analyzed usually show 1 per cent or more of potash. A small percentage of potash in such a mixture is probably not commercially extractable, and there is no good reason for the belief that such salts found at the surface indicate any richer deposits in depth.

Saline muds, even if they contain relatively high percentages of potash salts, are of doubtful value for the extraction of potash. A mud which contains 5 per cent of total saline matter would require the digging, mixing, and draining of 20 tons of raw material for a theoretical total extraction of 1 ton of crude salts. In practical operation this efficiency could never be even approached. From these crude salts the potash must then be extracted if it is to be marketed as potash. The low value of the final product appears to make such an undertaking impracticable.

Potassium-bearing brines, derived from massive beds of crystalline salts, however, may offer greater promise. The chemistry of extracting the potash seems to present some difficulties that have not yet been overcome in practical tests on a large scale. Such an enterprise doubtless must involve costly equipment and technical skill if it is to be successfully developed. Similar problems have been solved elsewhere, and there are assurances from various sources that practical methods have been found for the extraction of the potash here.

On the supposition that large deposits of buried salines exist in certain areas of concentration in the Great Basin, it still remains to be proved whether or not the potash-enriched portions of such deposits can be found. The hypothesis that these portions can be found is based principally on the assumption that the important segregation will be in the form of a residual brine, which, if free to flow, may be tapped and pumped from any point within the saline deposit and would therefore be easily found by random drilling, which might fail to strike local concentrations in solid form.

PROSPECTING FOR POTASH IN DEATH VALLEY, CALIFORNIA.

By Hoyt S. Gale.

INTRODUCTION.

In accordance with one of the first plans suggested under the governmental search for domestic sources of potash salts, a preliminary examination and test of the saline deposits in the floor of Death Valley was made during the winter of 1912–13. Four wells were drilled, three in the area of smooth salt in the lowest depression of the valley and the fourth about 20 miles north of the others. These borings are believed to have furnished the first information that has been obtained concerning the character of the deposits underlying the valley.

Reports state that practically the entire area in Death Valley has lately been located in "potash" claims, presumably as association placers, but in blocks of very large area. It is said that a single tract of 17,120 acres, known as the Kali property, was located in May to July, 1912, on the lowest part of the valley. Other groups both north and south of this tract have subsequently been taken up.

SALINE DEPOSITS IN DEATH VALLEY.

A vast amount of saline material is accumulated on and beneath the floor of Death Valley. A central area of crusted salt lies in the lowest part of the valley, extending for many miles from north to south. At the very lowest part of the valley, or so-called sink, there is an irregular area several miles across which is usually a smooth field of snowy white salt. Occasionally this is flooded by storm waters, which subsequently evaporate and again leave the surface crusted with white salts. Beyond the smooth salt to the north and south are the fields of rough salt. These differ from the area of smooth salt principally in the fact that the salt crust, not having been recently flooded and wholly redissolved, has been gradually broken into cakes and tilted at various angles, probably by expansion due to the growth of crystallization, thus producing a surface so rough that it is extremely difficult to traverse. A rim of soft mud lies between the main salt fields and the valley margin, this part also being occasionally flooded by storm waters and kept wet by the seepage of ground water from the marginal slopes. Beyond

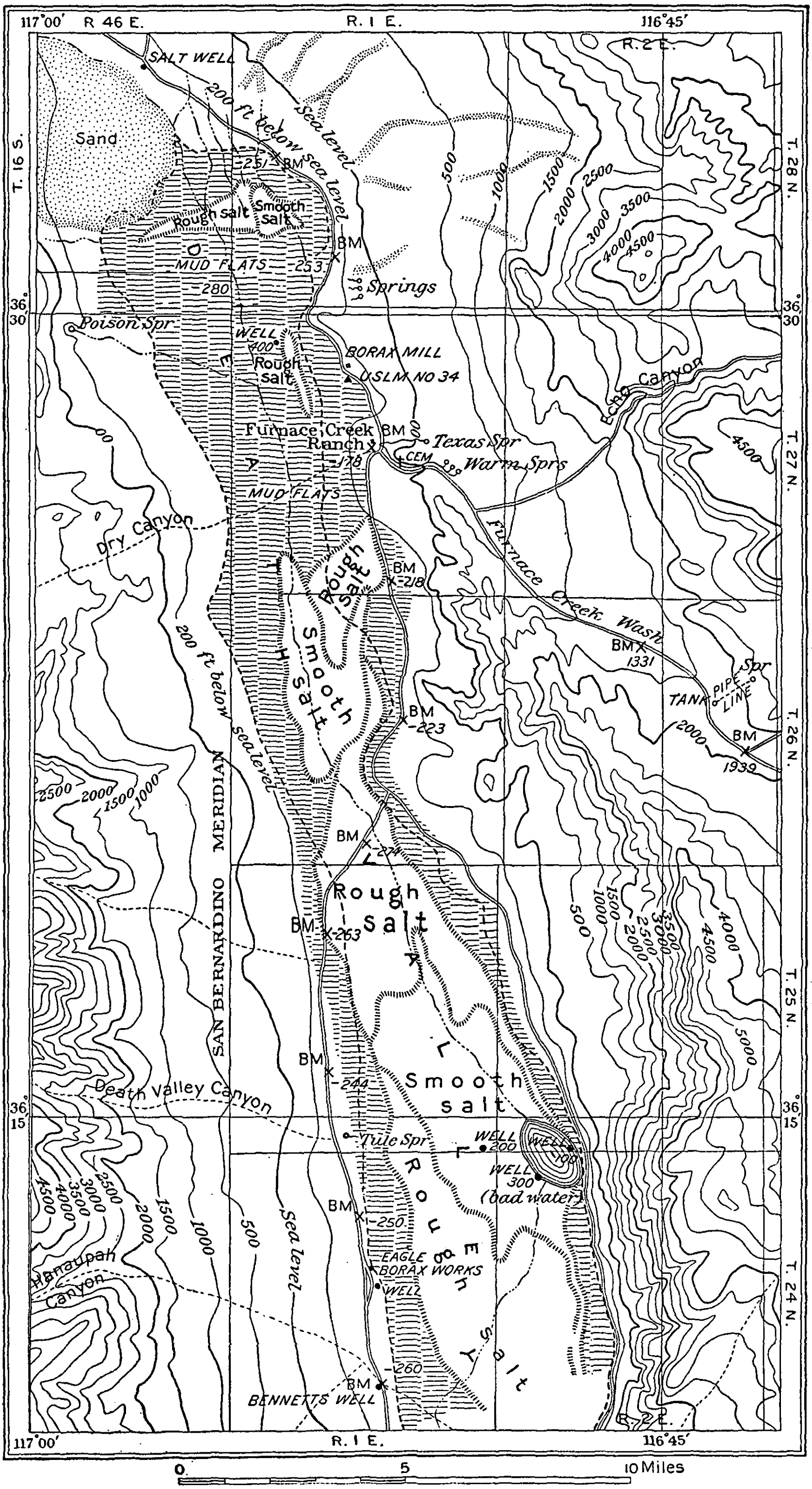


FIGURE 37.—Map showing salt deposits in Death Valley, California, and location of four wells drilled by the Geological Survey.

the mud rim are sand dunes and alluvial slopes of rock débris such as characterize these desert regions generally.

The outlines of these types of surface deposits are represented in the accompanying map of a portion of the valley (fig. 37), which is based on data collected by Charles E. Watson for the Geological Survey at the time the wells were being drilled. The location of the wells is also indicated.

SOURCE OF THE SALTS.

The salt deposits on the floor of Death Valley are believed to be explainable as the natural accumulations of salines from the normal drainage waters of country of this character and so do not differ in any essential respect from saline deposits in other desert basins in this general region. The fact that Death Valley is the final area of concentration for a very extensive drainage system is thought to explain the large extent and supposed depth of the deposits. Death Valley is known as the "sink" of Amargosa River, as it receives the periodic flood waters of that large drainage channel as well as numerous lesser tributaries. It appears, however, that Death Valley has also received similar flood-water drainage from Mohave River, for the present terminus of the Mohave drainage system lies in Soda Lake, a shallow evaporation pan separated from the Amargosa only by a very low divide. It has been suggested by several investigators that a part or all of the salines accumulated in Death Valley may have been derived from bedded saline deposits which are known to exist in at least one place in the adjacent Tertiary formations. These Tertiary beds, having been uplifted and exposed to erosion, are supposed to have contributed to the salines that found their way into the bottom of the valley. Doubtless a deposit of bedded salt, such as is known to exist, may have furnished a portion of the accumulated salines in Death Valley, but certainly it does not appear necessary to invoke such an explanation for this one occurrence, in view of the fact that deposits similar in type to those of Death Valley, on scales more or less proportionate to the present or former drainage areas of the respective basins, are common throughout the Great Basin region. The salts deposited on the floor of Death Valley are therefore assumed to be chiefly the accumulation and concentration of the salines dissolved in natural drainage waters that have evaporated there.

ANALYSES.

Prior to the present work the only published analyses of the salt in Death Valley, so far as the writer is aware, were one made by Oscar Loew[1] from a sample collected by Lieut. R. Birnie, jr., and a second made in the Geological Survey laboratory[2] from a sample collected by M. R. Campbell.

[1] Wheeler, G. M., Ann. Rept. U. S. Geog. Surveys W. 100th Mer., 1876, p. 176.

[2] Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: Bull. U. S. Geol. Survey No. 200, 1902, p. 18.

They are as follows:

Analysis of salt from Death Valley, Cal.

["Deposit 1 to 3 inches deep and covering many square miles."]

NaCl	95.49
Na_2SO_4	2.78
$CaSO_4$	.27
$MgCl_2$	Trace.
	98.54

In the analysis the sample was freed of its moisture in order to facilitate the comparison with other similar analyses.

Analysis of surface salt from Death Valley, Cal.

[George Steiger, analyst.]

NaCl	94.54
KCl	.31
Na_2SO_4	3.53
$CaSO_4\ 2H_2O$	.79
Moisture	.14
Insoluble residue	.50
	99.81

The sample collected by Campbell came from the middle of the area of the rough salt crust on the road between the Furnace Creek ranch and Bennett Wells, where the crust is nearly 3 miles wide.

During the recent explorations by the Geological Survey 83 samples, chiefly of the brines and deposits underlying the surface, have been taken, and some of these have been analyzed. The results available refer particularly to the potash content and are as follows:

Analyses of potash in natural brines from Death Valley, Cal.

[W. B. Hicks and R. K. Bailey, analysts.]

Sample.	Depth at which sample was taken (feet).	Total salts (ignited residue) (percentage of original sample).	Potash (K_2O) in total salts expressed as percentage of ignited residue.	Potassium expressed as percentage of KCl in original solution.
Ground water in the salt crust at the "sink"	0.5	28.19	3.43	1.53
Water in open "pothole"	.5	27.47	1.20	.52
Do	9.5	27.48	1.18	.51
U. S. G. S. well No. 100	6.0	27.87	2.85	1.27
Do	24.0	28.64	2.22	1.01
Do	29.0	28.96	2.35	1.09
Do	52.0	28.66	2.01	.91
U. S. G. S. well No. 200	32.0	28.33	1.54	.69
Do	38.0	29.16	1.78	.82
Do	70.0	29.96	2.48	1.18
U. S. G. S. well No. 300	1.0	27.78	2.05	.90
Do	30.0	27.91	1.68	.74
U. S. G. S. well No. 400	32.0	28.77	2.23	1.02
Do	38.0	28.73	2.12	.97
Average	....	28.42	2.08	.94

These are all essentially saturated brines, the principal dissolved constituent being sodium chloride. The potash content is not unusual in any way, being about the average generally found in natural brines or saline residues in the desert basins.

More complete analyses were subsequently made of several of the brines in the foregoing table, showing the general composition of the saturated brines in the lowest part of these deposits.

Analyses of brines from Death Valley, Cal.

[R. K. Bailey, analyst.]

	Depth (feet).	Cl.	SO_4.	B_4O_7.	Ca.	Mg.	K.	Na.	Total salts.
Well No. 200	32	53.07	7.93	0.42	0.07	0.05	1.29	37.17	28.50
Do	38	46.81	14.81	.44	....	.05	1.35	36.54	29.95
Do	70	47.91	12.67	1.01	....	.08	1.95	36.38	29.67
Well No. 300	1	55.74	5.05	.37	....	.04	1.62	37.18	27.71

Potash analyses of all the solid samples collected from one of the wells drilled in the lowest part of the valley were made in the Geological Survey laboratory are quoted in the following table. This well was selected for illustration, as its log and the preliminary tests made on the brines obtained from it and the other wells seemed to indicate that it would be fairly representative:

Potash analyses of solid samples from well No. 200, Death Valley, Cal.

[R. K. Bailey, analyst.]

Field No. of sample.	Depth (feet).	Loss of moisture on drying (per cent).	Total salts (ignited residue; per cent of original sample, dried at 105°).	Potash (per cent of total salts), expressed as—		
				K.	K_2O.	KCl.
32	0	7.79	87.21	0.18	0.22	0.35
33	2	28.85	26.45	2.72	3.28	5.20
34	8	11.49	68.60	.28	.34	.54
35	13	12.31	77.60	.25	.30	.47
36	17	17.47	17.57	1.62	2.10	3.09
37	21	18.10	40.51	.72	.86	1.37
38	24	30.72	21.47	1.87	2.25	3.56
39	30	20.76	94.42	.13	.16	.25
40	32	11.91	83.50	.15	.18	.28
41	37	17.30	76.71	.34	.41	.64
42	41	17.01	70.42	.47	.57	.90
43	43	22.72	40.60	.80	.96	1.53
44	46.5	25.53	24.67	.16	.20	.31
45	49.5	28.41	26.18	1.64	1.98	3.14
46	63	27.17	82.35	.52	.63	.99
47	70	21.41	67.90	.47	.57	.91
48	72	15.15	99.70	.08	.11	.16
49	74	15.24	79.45	.23	.27	.43
50	76	20.71	64.90	.54	.65	1.03
51	78	20.82	67.85	.48	.58	.92
52	81	23.80	76.90	.44	.53	.84
53	85	12.35	80.65	.22	.25	.40
54	87	16.33	77.90	.28	.34	.55
55	92	23.28	77.36	.42	.50	.79
56	....	15.66	81.80	.33	.39	.62
57	94	16.05	80.55	.52	.63	.99
58	96	11.65	39.45	.47	.57	.90
59	102	17.70	78.90	.31	.37	.59
Average	....	18.84	64.70	.59	.72	1.13

Thus the solid material of the deposits underlying the lowest part of the valley, exclusive of the flows in the water-bearing strata, to a depth of 100 feet may be assumed to average about 19 per cent of moisture, and after this has been dried out under conditions approximately normal for the locality, the dried material averages about 65 per cent of soluble salts. Of these soluble salts only about 0.72 per cent has been shown to be potash (or 1.13 per cent potassium chloride, the form in which the salt is doubtless present in this deposit).

WELL LOGS.

The logs of all the wells bored are given in full below from the records kept by Charles E. Watson.

Log of United States Geological Survey boring No. 100, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt, 1½ inches thick on surface		
Clay, light brown, containing crystals	10	10
Clay, light brown, smooth	4	14
Mud, brown, containing hard salt crystals	1	15
Salt and dark-brown clay	1	16
Clay, dark brown, containing crystals	4	20
Clay, dark green, containing crystals	3	23
Mud, soft, black, containing crystals	3	26
Salt, hard strata (required drilling with churn bit)	2	28
Clay, smooth, black	4	32
Clay, black, containing crystals (strata of salt 1 to 3 inches thick from 32 to 39 feet)	7	39
Clay, light gray and black, mixed, containing crystals	1	40
Salt, hard (required drilling)	1	41
Clay, light gray and black, containing many crystals	5	46
Clay, black, containing crystals	5	51
Salt crystals and a little clay, light	1	52
Clay, black, containing crystals (salt strata 1 to 3 inches thick from 52 to 56 feet; very hard salt, from 48 to 49 feet 2 inches)	4	56
Water or brines encountered:		
W. S. No. 1, salty, strong flow within 1 foot of surface		6
W. S. No. 2, salty, strong flow within 18 inches of surface		24
W. S. No. 3, salty, strong flow within 2 feet of surface		29
W. S. No. 4, salty, seepage water		52

Log of United States Geological Survey boring No. 200, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt (6 inches thick on surface)	0.5	
Clay, soft, light brown, containing crystals	3.5	4.0
Salt, very hard	2.0	6.0
Mud, soft, brown, containing coarse crystals	11.0	17.0
Mud, smooth, brown	.5	17.5
Salt, in layers 1 inch thick	.5	18.0
Mud, soft, brown, smooth	3.0	21.0
Mud, light brown, sticky, containing crystals	3.0	24.0
Mud, soft, brown, containing crystals	3.0	27.0
Salt, hard	2.5	29.5
Clay, tough, brown	.5	30.0
Salt, hard, drilled	1.0	31.0
Mud, soft brown, containing crystals	.3	31.3
Salt, hard	.7	32.0
Clay, dark, containing crystals	4.5	36.5
Salt, hard	1.5	38.0
Mud, black, containing crystals and hard salt strata 1 inch thick	1.5	39.5
Salt, hard, black	2.0	41.5
Mud, black, containing crystals	1.5	43.0
Salt, hard	.2	43.2
Clay, black, containing crystals	2.3	45.5
Salt, hard, black	.5	46.0
Clay, light gray and black mixed, containing crystals	5.0	51.0

Log of United States Geological Survey boring No. 200, Death Valley, Cal.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt, very hard	1.5	52.5
Clay, dark, containing crystals	.5	53.0
Salt, hard	.5	54.0
Clay, tough, dark	.5	54.5
Salt, very hard, hardest yet encountered, black	15.5	70.0
Clay, tough, dark blue, containing crystals	1.0	71.0
Salt, very hard, black	5.0	76.0
Clay, dark blue, containing crystals	2.5	78.5
Salt, hard, black	1.0	79.5
Clay, dark blue, containing crystals	6.2	85.7
Salt, hard	1.0	86.7
Clay, dark blue, containing crystals	3.8	90.5
Salt, very hard	1.5	92.0
Clay, very tough, dark blue, containing crystals	4.0	96.0
Clay, tough, black, containing crystals	8.0	104.0
Water encountered:		
W. S. No. 1, black salty water, came within 2 feet of the surface		32.0
W. S. No. 2, salty, nearly clear, came within 1 foot of the surface, strong flow; with 8 feet of section pipe on hand-pump well flowed 5 gallons in 2 minutes		38.0
W. S. No. 3, seepage water in well after standing over night		70.0

Log of United States Geological Survey boring No. 300, Death Valley, Cal.

	Thickness.	Depth.
Salt, 1½ inches thick, on surface.	*Feet.*	*Feet.*
Mud, light brown, containing coarse salt crystals	1.5	1.5
Salt, layer 2 inches thick, with flow of brine at bottom.		
Mud, soft, brown (small flow of warm water at 30 feet)	29.0	30.5
Mud, yielding seepage of water	2.5	33.0
Clay or mud and crystals of salt	1.5	34.5
Salt	.5	35.0
Mud, black, and crystals of salt	1.5	36.5
Salt	.5	37.0
Mud, black, and crystals of salt (water all shut off and auger cut without seepage)	15.0	52.0
Salt	.3	52.3
Clay, black, with occasional thin salt layers	3.7	56.0
Salt, crystalline, hard, containing layers of black clay mixed with salt crystals 1 to 4 inches thick at intervals of about 2 feet	8.5	64.5
Mud	.5	65.0
Salt, crystalline, apparently solid	13.0	78.0
Mud	.2	78.2
Salt, crystalline	3.8	82.0
Clay, black	1.0	83.0
Salt, crystalline	2.0	85.0
Clay, black, containing salt crystals (no water encountered in the lower part of the well)	10.5	95.5
Water encountered:		
W. S. No. 1, surface, salty, strong flow, 6 inches from surface to		5.0
W. S. No. 2, warm, salty, came within 1 foot of surface		30.0

The foregoing log shows the thickest bed of crystalline salts recorded.

Log of United States Geological Survey boring No. 400, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, borax soda and brown mud	0.5	0.5
Mud, light brown, with a few flat crystals	7.5	8.0
Mud, tough, brown, smooth	4.0	12.0
Clay, light brown, smooth	5.0	17.0
Mud, dry, brown, smooth	9.0	26.0
Clay, light blue, containing crystals	5.5	31.5
Salt, hard	2.0	33.5
Clay, tough, blue, few crystals	1.5	35.0
Salt, hard	12.0	47.0
Water encountered:		
W. S. No. 1, salty, strong flow within 2 feet of surface		32.0
W. S. No. 2, salty, warm, strong flow within 2 feet of surface		38.0

These wells show that within the limits of depth attained (104 feet in the deepest well) the valley is underlain by alternating layers of mud or clay and rock salt. Salt brines were encountered at several horizons, but not under such pressure as to cause them to rise and flow out on the surface. The greater part of the beds passed through consist of compact, gummy clays, including salt crystals, apparently quite impervious to the flow of water. In general, the flows of brine appear to be derived from layers just beneath the beds of crystalline salts and rarely come as seepage from within the muds.

GENERAL CONCLUSIONS AS TO THE OCCURRENCE OF POTASH.

The evidence as to saline deposits and especially the possible segregation of potash in Death Valley may be reviewed as follows:

No shore markings or other evidence of former deep submergence of Death Valley have yet been discovered. It appears that the deposits laid down in this valley have been chiefly the result of temporary shallow submergences and alternate desiccations. Thus the deposits that make up the floor of this valley are supposed to have been built up layer by layer, the salts having crystallized from the water evaporated from the temporary shallow lakes and having been occasionally buried in mixtures of sand and silt, including more or less saline material swept in by floods. This process is going on at the present day.

A vast amount of saline material is accumulated in the bottom of this valley, but the mode of its deposition is probably not favorable to selective crystallization on a large scale. Segregation of potash or any other portion of the soluble constituents of the waters may have taken place to a slight extent in the individual salt-crust layers, but under the conditions described any such differentiation is likely to have been restricted to the individual layers as units and therefore has occurred on a scale so small as to be of doubtful practical importance. It seems evident that unless a vast body of saline material has been deposited at one time during a single period of desiccation there would be little chance for the various dissolved constituents to become segregated from one another on a large scale. There is no record of the drying up of a single large lake of saline waters in Death Valley. Although it is possible that the shores of such a lake might have been completely buried, the assumption that this may have happened must be purely a matter of speculation. Similar reasoning may apply to many other areas in the desert-basin region. Great interior lakes have existed in certain areas and may have dried up under such conditions that the salts they contained were deposited in a great body and the potash and other minerals in the waters were by crystallization to a certain extent segregated in some portion of the deposits. Searles Lake contains a deposit of salt evidently produced in this way, and others may be found, although they are not now exposed at the surface. It does not appear that there is much theoretical justification for the belief that such deposits are present in Death Valley. It is of course possible that the present conclusions are based on insufficient negative evidence, and for this reason any further drilling that may be carried on by private claimants in the Death Valley region should afford information of much importance and interest.

SALT, BORAX, AND POTASH IN SALINE VALLEY, INYO COUNTY, CALIFORNIA.

By Hoyt S. Gale.

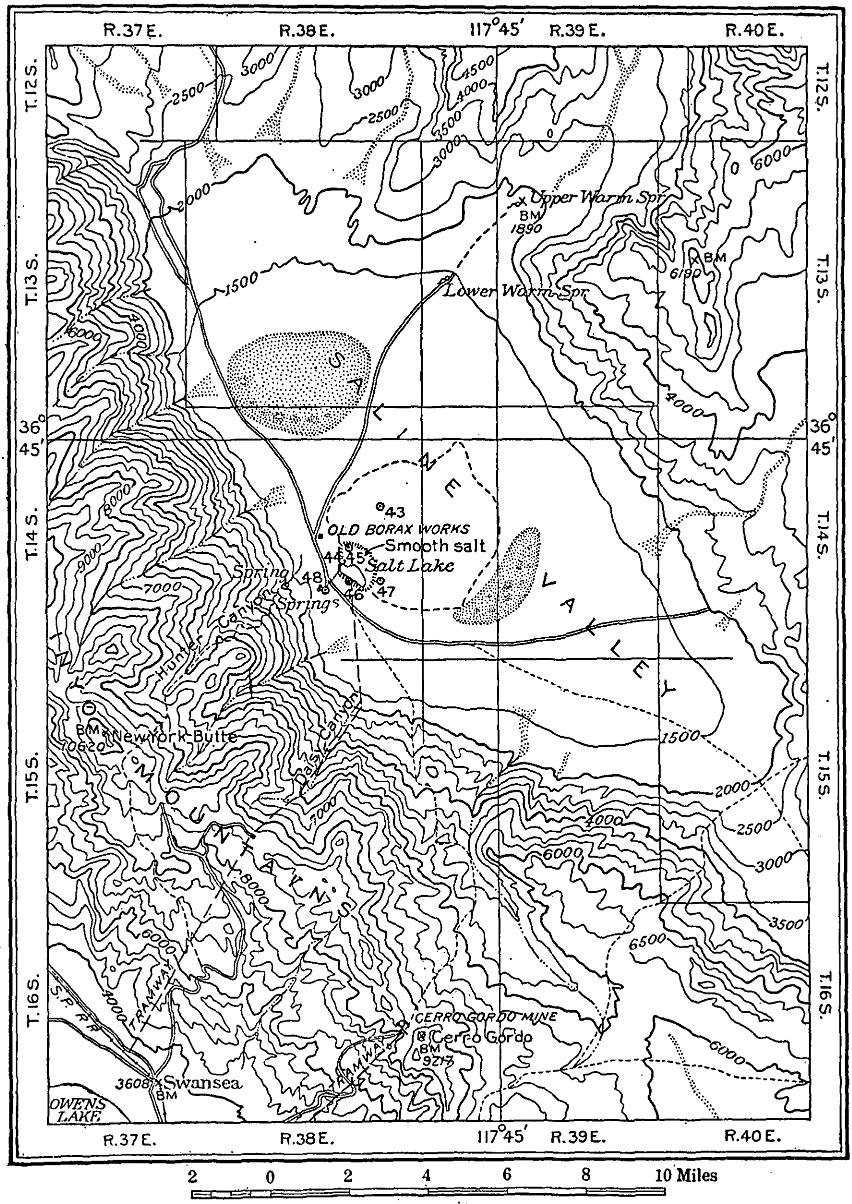
PRESENT INTEREST IN THE DEPOSITS.

A stock company recently formed to develop the salt from Saline Valley, Cal., and put it on the market has spent a considerable amount of money in building a tram which is to extend from Swansea, on the narrow-gage railroad east of Owens Lake, across the Inyo Range, and down to the margin of the salt marsh in Saline Valley. Construction on this difficult piece of engineering work was well advanced at the time of the writer's visit, and there appears good assurance that its operation will be mechanically successful. The large amount of work done for the development of this salt deposit perhaps justifies a more extended consideration of the nature of the deposit and the industrial conditions affecting its utilization than is at present feasible, but the following brief account is given from the data already at hand.

The deposit was examined by the writer October 27, 1912, for the purpose of procuring samples of the salt for analysis to determine whether or not it contains soluble potash and for such incidental data as might be obtained bearing on the deposition of desert-basin salines.

LOCATION.

The shortest route into the valley from the railroad is by trail over the Inyo Range from Keeler or, rather, from a siding called Swansea, on the Nevada & California branch of the Southern Pacific system about 3 miles north of Keeler. A wagon road crosses the range into Saline Valley from Owens Valley, to the northwest, but with an ordinary team the trip requires two days, and no water is to be had across the range. The trail from Swansea, following the route of the recently built tram, makes a climb of 5,000 feet from Owens Valley to the summit, where the tram crosses, and a descent of 7,500 feet into Saline Valley on the east side. The trip in either direction can readily be made in a day so long as the trail remains in good condition, although it is a somewhat strenuous day's work. The climb up or down the east side of the Inyo Range is over a remarkable rock-cut trail, picturesque in the extreme from its ruggedness and the precipitous



Contour interval 500 feet

FIGURE 38.—Map of Saline Valley and vicinity, California, showing location of salt deposits.

gorges and rocky slopes it discloses. The distance from Swansea to the camp in Saline Valley is only about 12 or 13 miles by this route.

SALT DEPOSITS.

The salt deposits of Saline Valley occupy the lowest part of the depression, which, like other desert basins, is completely inclosed by high drainage divides and has no outlet. Surface and ground waters derived from this area flow toward the central depression, which has probably been submerged, though perhaps only to shallow depths and for short epochs. No terraces or traces of upper shore marking were observed. The central or playa deposit of salts and mud, lying almost flat at the bottom of the valley, occupies approximately 12 square miles. Of this only about 1 square mile is composed of a smooth, white, salt crust containing a small pond of salt water. It is the white salt from this surface that it is proposed to harvest and ship to market. Approximate outlines of these areas are shown on the accompanying map (fig. 38), which is taken from the recently completed map of the Ballarat quadrangle. The playa surface beyond the white salt is, like that of marginal salt crusts in some other desert basins, a rough expanse of broken and tilted salt blocks which, having been partly dissolved by storm waters, now stand with an exceedingly sharp, craggy surface. The rough salt has a dirty brown color, doubtless due to the dust which is blown upon it in windstorms and which does not have an opportunity to settle out by occasional floodings and partial solution such as occur in the area of smooth salt.

The salt company's prospectus states that no refining or treatment other than grinding will be needed before placing the salt on the market, and it is assumed that in the main the product to be shipped will be gathered by scraping on the surface of the smooth salt. At the time of the writer's visit a great amount of salt had been piled in stacks ready for transfer to the tram for shipment when that shall have been completed. Samples of the undisturbed salt in these stacks were collected by the writer, with the intention of making a representative average sample of the salt on the ground. Portions were taken from the inner part of six of these stacks from various parts of the field, and these were combined and later mixed, quartered, and analyzed. The following analysis of this sample was made by R. K. Bailey, in the Geological Survey at Washington.

Composition of average salt sample from stacks in Saline Valley, Cal.

Ca	0.00		
Mg	.00		
CO_3	.00		
HCO_3	.00		
H_2O	.12		0.12
Insoluble	.17		.17
Cl	59.76	=NaCl	98.52
Na	39.09	=Na_2SO_4	1.02
SO_4	.95		
K	.11	=K_2SO_4	.37
	100.20		100.20

This analysis shows the salt to be of rather exceptional purity for an entirely natural product. One of the principal factors in its favor is the absence of soluble salts of magnesium or calcium, which would, if present as chlorides, tend to make the salt subject to caking on account of the attraction they have for moisture. With the exception of the small insoluble residue, which is doubtless dust blown in by the wind, the sulphate is the only impurity

Very little is known of the thickness of the deposit, as it appears from reports that no satisfactory drilling has been done. Shallow holes dug in the surface of the white salt crust for the purpose of obtaining samples of the underlying brines show a surface thickness of 4 inches of a loose-textured, porous white crystalline salt, below which is a layer of dark-greenish or almost black saline mud several inches thick. Other layers of hard salt are encountered below this mud, so that it is difficult to dig the deposit with an ordinary shovel, not only on account of its hardness but also because the pit immediately fills with the freely flowing brine.

The ground water stands so high that either the salt crust is barely submerged or water or brine will fill any hole dug in the salt almost at once, rising practically to the surface level. Thus the salt crust is not so hard as it would be on a dry surface and is readily worked. The salt on the surface of the salt flat is gathered by raking or scraping it into heaps while in a wet or slushy condition. The crystals become dry in the stacks and are benefited if washed by an occasional rain. The outer surfaces of the stacks become "sunburned" or somewhat darkened on exposure. This is probably due to the dust swept over them by the wind.

Although it is stated that the principal harvest is that of the natural salt crop, which continuously replaces itself, a series of evaporating vats have been built about the southwest margin of the salt flat and pond, where, by evaporation of the liquor of the lake or recrystallization of the less pure salt from the area surrounding the white salt, the production can be increased.

MARKET FOR THE SALT.

The total production of salt in California in 1911 was approximately 150,000 short tons, the average value of which is listed as $3.65 a ton. The price quoted for California salt is considerably higher than the average price for salt in the United States as a whole. The finer dairy salt is sold at prices higher than that given for the average, but much of the coarse solar salt is sold below that price. The market for the refined salt is of course more limited than that for the coarse. It has been estimated that 12,000 tons of refined salt from the Eastern or the Middle Western States, such as Kansas and Michigan, are shipped for use on the Pacific coast annually. Other than this the California and other western markets are now supplied chiefly by the solar evaporation plants already established on San Francisco Bay, at San Pedro, and elsewhere, and by the smaller output from natural deposits of the desert-basin type.

POTASH TESTS.

Besides the sample of surface salts, a number of samples of the ground solutions were collected at several points about the salt flat, with the special object of testing them for potassium compounds. The results of the tests were practically negative, as shown in the following tabulation of results:

Potash analyses of brines from Saline Valley, Cal.

[Nos. 43-46 by R. K. Bailey; Nos. 47 and 48 by W. B. Hicks.]

Sample No. [a]	Total salts (ignited residue).	Potassium in the total salts.		
		K.	K_2O.	KCl.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
43	29.77	1.29	1.56	2.47
44	28.10	.78	.94	1.48
45	28.05	.81	.99	1.55
46	28.77	1.29	1.56	2.47
47	28.26	.95	1.15	1.82
48	.10	.05	.06	.10

[a] For location see fig. 2.

All these samples except No. 48 are brines collected in the salt flat, the locations being shown on the map (fig. 38). No. 48 was a sample of the natural flow of lukewarm water from the large spring above the salt company's camp, taken in the center of the open stream just below the junction of the several flows. This is the water that drains into the southwest corner of the salt flat and probably supplies the pond of open water. The total flow from this spring, several hundred gallons a minute, is said to vary considerably with the rainfall in the mountains.

It appears that there is little or no evidence from these tests of an important segregation of potash in the residual solutions near the surface. There is a possibility that better results might be discovered by drilling, but from general considerations it is not now supposed likely that a segregation of the potash would be found on a sufficiently large scale to justify much expense in exploration.

BORAX FROM SALINE VALLEY.

The borax industry in Saline Valley is probably a thing of the past. It is said that borax lands were first located in the valley in 1895. Before 1907 the salt crust from certain parts of the flat which are richer in borates than the rest had been collected and dissolved in tanks of hot water and the borax crystallized from the solutions, which became supersaturated with that salt upon cooling. The following account of this process [1] has been given with special reference to Saline Valley, but the procedure was similar at many other deposits:

> All the manipulation that is required is to shovel off the surface of the marsh to a depth of 18 inches and cart the material to long hemispherical wrought-iron pans set on arches of stone, fired beneath with wood fuel obtained in the neighborhood. The pans are charged with water and the crude material thrown in and vigorously stirred with long poles, until, with the aid of heat, all of the soluble salts are dissolved. The fires are then withdrawn and the contents of the pans allowed to settle for 10 hours, when the liquor is drawn off into vats, where the borax crystallizes out. The mother liquor after six days is drawn off and the borax is taken out and packed into sacks for shipment.

For the heating of these tanks much of the grove of mesquite trees about the spring at the southwest corner of the salt flat had been cut and burned, but these trees are now replacing themselves by natural growth. The principal borax-producing plant was about a mile north of the present salt company's camp, and some of the buildings and old tanks are still there. There was another borax works on the opposite side of the valley, said to have been situated east of south from the lower hot springs noted on the map. It seems not unreasonable to assume that a part at least of the boric-acid content of these deposits is derived from the hot springs, although no analyses of these waters are known to the writer. Possibly the marked decrease in solubility of borate salts on lowering of temperature accounts for the localization of these salts reported in the saline deposits. Aside from the fact that the richer ore of borax known as colemanite has now displaced the material derived from dry lake deposits of this type, it is supposed that the richer borate-bearing portions of the salt crust have been largely worked over and exhausted.

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[1] Thorpe, Edward, Dictionary of applied chemistry, new ed., vol. 1, 1912, p. 508.

POTASH TESTS AT COLUMBUS MARSH, NEVADA.

By Hoyt S. Gale.

In February, 1913, the Geological Survey issued a press notice, giving some preliminary results of analyses of mud samples obtained in drilling on Columbus Marsh, near Coaldale, Nev. The saline muds from certain portions of the strata penetrated in the wells had been proved on testing to contain a much higher content of potash than is usually found in such deposits, and it was believed that the results were worthy of careful investigation, as they might lead to the development of a commercially important source of this material. The statements made in the press notice were in substance as follows:

During 1912 the explorations of the Survey geologists with hand-drilling apparatus were carried into Columbus Marsh, and six holes were sunk to depths ranging from 32 to 50 feet. The drilling was done by Charles E. Watson under the direction of the writer. A portion of the marsh was located for borax a good many years ago, and a very small area may have been patented, but the greater part of the playa is still public land. Prior to the Geological Survey prospecting no private interest had been shown in the possibility of developing potash deposits there.

Columbus Marsh is situated on or near the line between Esmeralda and Mineral counties, Nev. Coaldale is a railroad station at the southeast corner of the marsh, and the Tonopah & Goldfield Railroad skirts the eastern margin of the mud flat itself. The marsh covers an area of 35 or 40 square miles, roughly elliptical in outline, being about 9 miles in longest dimension from north to south and 6 miles or more in width. It is a broad mud plain with rough, lumpy surface—a typical playa, the lowest part of the basin of a distinct drainage system, a physiographic feature characteristic of the Great Basin region. Little salt shows on the mud surface except about the margins of the plain, where several borax-producing plants were located in the earlier days of the borax industry.

In the preliminary notice issued attention was directed particularly to the record of well No. 400, given herewith. The analyses of the muds sampled from this well show that the average 20-foot section from the depth of 18 to 38 feet contains 20.59 per cent of potash in the water-soluble portion of the samples. These mud samples, however, averaged only 5.96 per cent of water-soluble salts in the air-dried condition in which they were received at the laboratory. Water samples representing flows at a number of horizons associated with these high potash bearing muds had been collected during the drilling, but at the time the first press notice was issued these samples had been delayed in transit and had not reached the chemical laboratory. Naturally it was expected that the abundant water flows recorded in well No. 400 might prove to be highly charged with potash-rich saline material. From the outset, however, it has been clearly stated that "saline muds which contain only 5 or 6 per cent of total soluble material may not be commercially workable, even though 26 to 40 per cent of that total soluble portion may be potassium chloride," as had been shown in the record of this particular well. After the missing water samples were received and analyzed a second press notice was issued, giving the results.

With a few exceptions all the waters from the wells bored in Columbus Marsh were unexpectedly dilute. The compiled table of the tests is given in one of the following tables. Furthermore, the salts dissolved in these waters did not have so unusually high a potash content as the muds, showing thus a lack of correspondence to the results that had been obtained in the preliminary set of analyses. Probably the deposit warrants still further exploration, as the conditions can not be said to be thoroughly understood. The complete record of the analyses now at hand is as follows:

Analyses of mud samples from borings at Columbus Marsh, Nev.

[W. B. Hicks, analyst.]

Well No. 100, sec. 13, T. 2 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	Potash (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
100+1	1	3.62	3.04	3.67	5.80
100+3	6½	1.67	Undetermined.		
100+5	12	1.76	Undetermined.		
100+7	16½	1.69	Undetermined.		
100+9	25	1.87	Undetermined.		

Well No. 200, sec. 12, T. 2 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	K.	K_2O.	KCl.
200+ 1	½	18.56	0.34	0.41	0.65
200+ 2	1	9.39	4.75	5.72	9.03
200+ 3	3	6.12	4.46	5.37	8.50
200+ 4	5	5.72	6.51	7.85	12.41
200+ 5	6	5.55	6.62	7.97	12.61
200+ 6	7	4.67	5.62	6.77	10.71
200+ 7	23	6.15	6.91	8.32	13.17
200+ 8	25	8.41	7.42	8.94	14.15
200+ 9	29	8.06	8.46	10.07	16.13
200+10	31	9.45	6.88	8.29	13.12
200+11	36	8.31	7.19	8.51	13.72
200+12	38	8.42	6.17	7.43	11.76
200+13	40	7.10	6.61	7.97	12.60
200+14	44	17.83	3.12	3.76	5.95
200+15	49	22.30	1.88	2.27	3.59

Analyses of mud samples from borings at Columbus Marsh, Nev.—Continued.

Well No. 300, sec. 36, T. 3 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	Potash (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
300+ 1	1	14.10	3.79	4.57	7.23
300+ 2	3	16.02	4.65	5.60	8.86
300+ 3	5	14.70	2.93	3.53	5.58
300+ 4	10	18.80	2.82	3.40	5.37
300+ 5	15	19.64	4.14	4.99	7.89
300+ 6	20	21.60	4.69	5.65	8.94
300+ 7	23	14.74	3.81	4.59	7.26
300+ 8	27	19.83	3.78	4.56	7.21
300+ 9	31	19.44	2.40	2.89	4.58
300+10	35	20.63	3.05	3.67	5.82
300+11	40	16.01	3.67	4.42	7.00
300+12	45	26.91	2.89	3.48	5.50
300+13	50	15.13	4.34	5.22	8.26

Well No. 400, sec. 8, T. 2 N., R. 36 E.

400+1	1	17.30	1.67	2.01	3.18
400+2	3	9.07	2.55	3.07	4.85
400+3	4½	8.88	2.48	2.99	4.73
400+4	9	10.15	2.95	3.55	5.62
400+5	12	1.93		Undetermined.	
400+6	18	5.17	16.64	20.05	31.72
400+7	27	6.30	20.90	25.18	39.83
400+8	30	6.17	13.69	16.49	26.09
400+9	33-38	6.22	17.12	20.63	32.64

Well No. 500, sec. 32, T. 3 N., R. 36 E.

500+ 1	1	15.50	2.47	2.98	4.71
500+ 2	3	14.62	3.19	3.85	6.09
500+ 3	6	14.78	2.38	2.87	4.53
500+ 4	12	12.20	3.70	4.46	7.05
500+ 5	16	12.12	3.60	4.43	7.01
500+ 6	20	12.40	4.15	5.00	7.90
500+ 7	25	11.95	3.89	4.69	7.42
500+ 8	28	11.79	6.23	7.51	11.87
500+ 9	34	12.62	6.69	8.06	12.75
500+10	42	12.15	6.65	8.01	12.67
500+11	48	11.10	4.25	5.12	8.11

Well No. 600, sec. 15, T. 3 N., R. 36 E.

600+ 1	Surface.	19.12	1.37	1.65	2.62
600+ 2	4	14.48	4.57	5.50	8.70
600+ 3	10	12.83	2.41	2.91	4.60
600+ 4	17	17.50	2.69	3.21	5.09
600+ 5	20	12.61	3.37	4.06	6.42
600+ 6	25	12.30	5.16	6.22	9.84
600+ 7	29	10.51	4.44	5.35	8.47
600+ 8	32	11.85	5.18	6.24	9.87
600+ 9	37	10.60	5.94	7.15	11.32
600+10	38	15.20	5.66	6.82	10.79
600+11	46	11.04	5.80	6.98	11.05

NOTE.—Mud samples from wells Nos. 700 and 800 not yet analyzed.

Analyses of water samples obtained from borings by United States Geological Survey at Columbus Marsh, Nev.

[W. B. Hicks and R. K. Bailey, analysts.]

Well No.	Depth (feet).	Soluble (per cent of original sample).	Potassium (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
300	17	23.73	1.57	1.89	2.99
400	10	1.86	2.87	3.45	5.47
400	16	.65	3.27	3.95	6.23
400	19	.54	3.72	4.49	7.10
400	29	.42	4.17	5.03	7.94
400	32	.44	4.93	5.96	9.41
400	38	.48	4.41	5.32	8.41
500	12	24.79	1.27	1.53	2.41
600	22	17.97	3.23	3.87	6.13
700	12	.54		Undetermined.	
700	17	.99		Undetermined.	
700	32	.68		Undetermined.	
800	6	5.23	1.74	2.09	3.32
800	16	.71		Undetermined.	
800	19	.61		Undetermined.	
800	30	.64		Undetermined.	
800	48	.82		Undetermined.	
800	74	.40		Undetermined.	

The logs of the wells show little of distinctive character in the deposits.

Well No. 100, drilled July 6 and 7, 1912, reached a depth of 32 feet, mostly in mud, more or less sandy, showing a layer of fine gravel at a depth of 25 feet. Water was encountered from 7½ feet down, samples being taken at 12, 17, 23, and 27.5 feet. At times sand flowed into the casings like quicksand.

Well No. 200, drilled July 8 to 10, 1912, started on a dry saline-mud surface, encountering a hardpan of cemented sand at a depth of 1 foot. Below this was found a moist, sticky mud containing some sand, from which there was a seepage of water. This had a disagreeable odor, like decaying swamp matter. At 18 feet a hard layer was encountered, light gray and sandy, without water, and this continued to 25 feet. Below this was a dark sticky mud yielding seepage water, containing crystals, in part very abundantly. Water continued to seep at intervals to the total depth of 50 feet 6 inches.

Well No. 300, drilled July 11 to 12, 1912, passed through light-colored to yellowish-green clay with some sand to a depth of 20 feet. Below this the record shows a continuous section of black clay, containing salt crystals in places. A 13-inch stratum of limestone was reported at 17 feet. The only water found was a very small seepage obtained at 17 feet. The total depth reached was 50 feet. This well was sunk by augering without using casing.

Well No. 400, drilled July 13 to 18, 1912, gave more trouble than any of the other wells put down. It was cased at all times, the augering and drilling being done in the casing and the casing being driven ahead as fast as it could be moved. The material passed through was mostly very wet, flowing in and filling up the casing from the bottom, like soft quicksand. After filling the casing this material packed very tight, requiring much labor to extract it. From a depth of 28 feet water rose in the casing within 4 feet of the surface. This water contained less than 0.5 per cent of dissolved salts. A coarse sand and fine wash gravel was reported at 32 feet, underlying which, according to the log, is "tough light clay, and below that 1.5 feet of rock, then tough clay and rock again; water rising within 2 feet of the surface. At a depth of 41 feet very hard rock was struck, in which an hour of drilling made no advance." The casing was then pulled. The mud samples obtained from the lower part of this well were those that have been reported to show on analysis exceptionally high results in potash. A number of water samples were collected at various depths, all of which proved on testing to be comparatively dilute, and the salts dissolved failed to show very exceptional potassium analyses.

Well No. 500, drilled July 19, 1912, reached a depth of 49.5 feet, showing almost entirely clay, generally moist, yielding but little water. A sample of water was collected at 12 feet and a seepage was noted from the depth of 15 feet.

Well No. 600, drilled July 20 to 22, 1912, reached a depth of 49 feet. This was sunk by augering mostly in clay, light colored in the upper 10 feet, the rest dark gray to black. Water was collected only at 22 feet.

Subsequent to the drilling of the first six wells, two wells of greater depth have been drilled by the Geological Survey in the vicinity of well No. 400. The following are the complete logs of wells Nos. 700 and 800, the analyses of the solid samples from which are not yet finished.

Record of United States Geological Survey boring No. 700, Columbus Marsh, Nev., in the southeast corner of sec. 5, T. 2 N., R. 36 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, salt crust, formerly worked for borax	0.3	0.3
Sand, light brown, moist	2.7	3.0
Sand and gravel, light brown, fine gravel, wet	1.0	4.0
Clay and sand, dark blue, wet	2.0	6.0
Clay and sand, black, containing crystals	6.0	12.0
Sand, black, soft muck, pumped	2.0	14.0
Sand, black, soft, full of fine crystals	3.0	17.0
Sand and gravel, fine, full of crystals	9.0	26.0
Quicksand	6.0	32.0
Water encountered:		
Water sand No. 1, black, stinking water, not salty		4.5
Water sand No. 2, seepage water, nearly fresh		12.0
Water sand No. 3, black, stinking, came within 4 feet of the surface, strong flow		17.0
Water sand No. 4, stinking, not salty, seepage		32.0

NOTE.—This well was in running sand from 3 to 32 feet.

Record of United States Geological Survey boring No. 800, Columbus Marsh, Nev., in the center of sec. 5, T. 2 N., R. 36 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, salt crust like that formerly worked for borax	0.5	0.5
Sand, light brown	1.5	2.0
Sand and clay, light yellow, dry	4.0	6.0
Clay, dark blue, smooth	1.0	7.0
Mud, black, smooth, sticky	5.0	12.0
Mud, black, smooth, wet	4.0	16.0
Sand, black, wet	3.0	19.0
Gravel, fine, containing crystals	1.5	20.5
Sand, fine, containing crystals	3.0	23.5
Clay and sand, light blue, containing hard, coarse particles	7.5	31.0
Clay, light gray, containing hard, coarse particles	4.0	35.0
Clay, black and yellow, containing hard, coarse particles	3.0	38.0
Clay, dark blue, containing hard, coarse particles, soft and wet	6.0	44.0
Clay, black, containing hard, coarse particles, soft and wet	3.0	47.0
Clay, light gray and black, smooth, soft, and wet	1.0	48.0
Clay and mud, black, pumped, containing coarse, hard particles, wet	5.0	53.0
Clay, smooth, black, dry	4.0	57.0
Clay, smooth, black and yellow, dry	4.0	61.0
Clay, smooth, light yellow, dry	4.0	65.0
Clay, smooth, dark bottle-green, dry	4.0	69.0
Clay, smooth, yellowish green and black, dry	5.0	74.0
Sand, quicksand, fine running sand	8.0	82.0
Water encountered:		
Water sand No. 1, salty, small flow		6.0
Water sand No. 2, black, not salty, medium flow within 4 feet of the surface		16.0
Water sand No. 3, little salty, clear, strong flow within 1 foot of surface		19.0
Water sand No. 4, seepage, black and foul		48.0
Water sand No. 5, little salty, medium flow within 3 feet of the surface		74.0

NOTE.—Water encountered at 19 feet was a very strong flow and fresh enough for horses to drink.

On January 16, 1913, the President withdrew from location and entry all the lands in Columbus Marsh that are supposed likely to contain valuable potash deposits. The withdrawal was made under the authority of the withdrawal act as amended on August 24, 1912. This amendment makes it effective as against all forms of entry under the mining laws of the United States except those that apply to metalliferous minerals. The withdrawal will enable the Government to proceed in due course to make further examination of these deposits or to prevent undesirable title complications in case Congress sees fit to provide a new and adequate law governing the disposal or lease of properties of this character.

SODIUM SULPHATE IN THE CARRIZO PLAIN, SAN LUIS OBISPO COUNTY, CALIFORNIA.

By Hoyt S. Gale.

The deposit of sodium sulphate in Soda Lake, in the Carrizo Plain, San Luis Obispo County, Cal., was briefly described by Arnold and Johnson[1] in 1909 shortly after the erection of a plant for the commercial development of the soda. The locality was examined by the writer in October, 1912, to determine whether or not soluble potassium salts are associated with the soda. The results of the tests made are negative as regards the occurrence of commercially important amounts of potash, but it seems desirable to publish a description of the deposit including in some detail the results of the recent tests.

There is at present no considerable market for sodium sulphate, or what is known in the trade as "salt cake," which is the product of the first step in the Leblanc process for the manufacture of sodium carbonate from sodium chloride. In this process salt cake is produced by the decomposition of sodium chloride with sulphuric acid, hydrochloric acid being a valuable by-product. At present, however, the Leblanc process has been almost entirely displaced by the ammonia process for the manufacture of soda, at least in the United States. Sodium sulphate is also used in glass making, for ultramarine, in dyeing and coloring, and to some extent in medicine (Glauber's salt). A use in paper manufacture has been suggested. Quotations on sodium sulphate in current trade journals range from 55 to 65 cents per 100 pounds for glassmaker's salt cake and 60 to 90 cents per 100 pounds for Glauber's salt in barrels. This is equivalent to $11 to $18 a short ton.

It seems hardly likely that natural sodium sulphate will be largely mined and used for the manufacture of either sodium carbonate or other sodium salts so long as extensive deposits containing the

[1] Arnold, Ralph, and Johnson, H. R., Sodium sulphate in Soda Lake, Carrizo Plain, San Luis Obispo County, Cal.: Bull. U. S. Geol. Survey No. 380, 1909, pp. 369–371.

carbonate and bicarbonate in large amounts are available. Therefore it is probably reasonable to assume that the utilization of such a deposit as that at Soda Lake depends on the demand or market for sodium sulphate as such or the evolution of some new processes requiring the soda in the form of sulphate. The possibility of such a demand may be sufficient to give to the deposit in the Carrizo Plain a certain potential value.

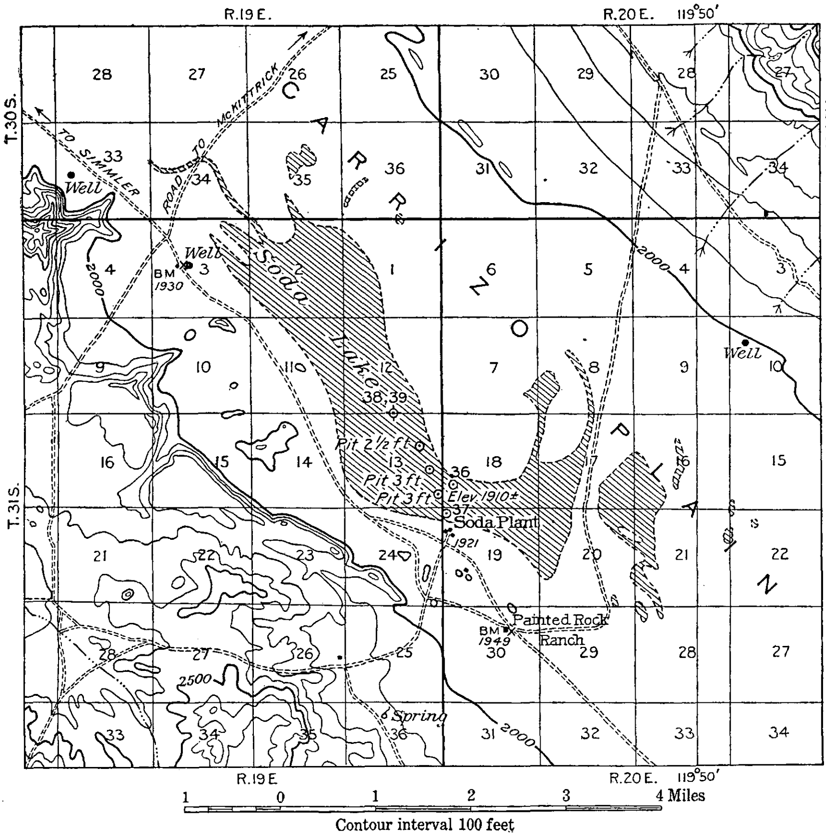


FIGURE 39.—Map of Soda Lake, San Luis Obispo County, Cal. From map of McKittrick quadrangle, U. S. Geological Survey.

The extent of the deposit is indicated in figure 39, from which it is estimated to be 2,800 to 3,000 acres. The lake is said to remain dry on the surface during the greater part of the time, although occasionally flooded to a shallow depth after storms. Its surface normally presents a broad, flat plain of white crystalline salts, ranging from a thin sheet about the margins to a deposit a few inches thick in the deeper parts, except that there is reported to exist a still deeper "channel" of solid salts, an example of which was noted at the outer terminus of the tramway leading to the flat. At the time of visit a number of pits had lately been dug on the salt crust, and several of these remained open, being filled with a saturated solution from which crystals of salts were being deposited about the margins. In these holes long, glassy, prismatic crystals form in the solution with chilling overnight, and these were assumed to be mirabilite (Glauber's salt), the sulphate of sodium crystallized with 10 molecules of water. On removal from the solution, however, these crystals rapidly effloresce and, losing their water, crumble to a fine white powder. The natural anhydrous sodium sulphate is thenardite, which has a crystal form distinct from that of mirabilite and is not so subject to alteration on exposure to the air. This has not yet been noted in crystalline form in this deposit.

The mass of the material underlying the surface crust or cake of salts is a soft mud of dark-greenish or grayish-black color, containing more or less of crystal salts and saline matter in solution. Numbers of large, blunt, distinctly terminated and double-ended crystals of a flat tabular form were noted about some of the excavations that had been made on the lake bottom. These had been found embedded in the mud under the salt crust. The crystals consisted of clear glassy material, containing an irregularly distributed dark, almost blackish, coloring matter, supposed to be included mud. They do not alter on exposure to the air like the crystals of hydrous sodium sulphate. A number of them were collected by the writer and determined by W. T. Schaller, of the Geological Survey, to be bloedite, a hydrous sulphate of sodium and magnesium. Schaller[1] describes the crystals as follows:

> The larger crystals have a dark, almost black appearance when the superficial covering of gray mud is removed, though the small crystals are nearly colorless, the black appearance being due to impurities. In places the larger crystals are likewise nearly colorless and translucent and in small pieces transparent. In fact, selected fragments are clear and glassy and, with the lack of cleavage, greatly resemble quartz fragments. * * * An analysis of selected pure material gave the following:

Analysis of bloedite from Soda Lake, Cal.

H_2O	21.37
MgO	11.93
Na_2O	18.26
SO_3	48.11
	99.67

The accompanying figure of a bloedite crystal (fig. 40) was drawn by Schaller from the specimens collected at this deposit.

[1] Schaller, W. T., Bloedite crystals, preliminary note: Jour. Washington Acad. Sci., vol. 3, No. 3, February, 1913, pp. 75, 76.

The only other occurrence of bloedite in the United States of which a record has been found is that in the Estancia Valley, N. Mex.[1]

The surface salt crust collected by Arnold and Johnson was analyzed by George Steiger, of the Geological Survey, as follows:

Analysis of saline crust from Soda Lake, Cal.

Insoluble	0.40
Al_2O_3	.04
MgO	1.66
CaO	.45
Na_2O	40.50
K_2O	.28
H_2O	3.65
CO_2	None.
SO_3	46.12
Cl	9.27
	102.37
Less oxygen	2.09
	100.28

A combination possible from the above composition may be calculated as 81.86 per cent of anhydrous sodium sulphate with 8.97 per cent of sodium chloride. A much purer sodium sulphate readily separates by crystallization as mirabilite from the saturated solutions of these salts, as is shown in the pits of open ground waters on the deposit. Little can be added to the geologic statement of the occurrence or manner of accumulation of these salts contained in Arnold and Johnson's description:

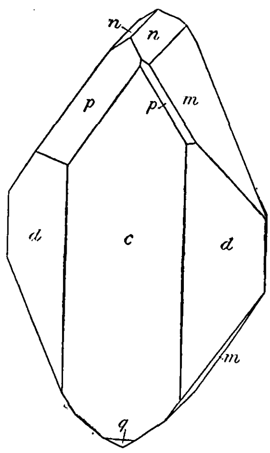


FIGURE 40.—Bloedite crystal from Carrizo Plain, Cal.

> The Carrizo Plain is a structural depression which has been faulted down between the Caliente and Temblor ranges and has been sufficiently covered by Pleistocene and possibly earlier débris to mask its real character. Faults, some of them very recent geologically, bound the plain along its northeast and southwest margins. The amount of folding and faulting which has taken place in this region is very great. This intense deformation has, in conjunction with denudation, exposed large areas of soft conglomerate, sandstone, and shale, particularly in the adjacent ranges, to the solvent action of rain, and thus through the agency of running water the soluble salts of these rocks have been transferred, in part, to the lowest portion of the plain. There they have been deposited, through evaporation of the solvent, in a series of saline beds, the chief constituent of which is sodium sulphate.

The basin has the appearance of having formerly belonged to the drainage basins of San Juan and Salina rivers. The lack of present

[1] Jones, F. A., Mines and minerals of New Mexico, 1904, p. 226.

outlet is doubtless due to tilting of this portion of the valley in fault blocks so that a former outlet to the northwest has been cut off, and as evaporation exceeds the rainfall the basin does not appear to have ever been filled to overflowing. A rise of water level of less than 200 feet at the present time would establish an outlet to the northwest. No terraces more than a few feet above the present flat were observed. The cut banks and terracelike margins of the dry lake bottom suggest the alluvial filling of a former stream channel without great modification of the original topography. Even the deeper channel in the salt deposit itself suggests a former continuous drainage channel passing across this area. If this is so, the saline and playa deposits may be of comparatively recent geologic age. The front of the Temblor Range, to the northeast, is apparently terraced, but the terraces are clearly the offsets of faulted blocks, the evidence of recent movement in places being quite distinct.

The following are the results of tests for potash salts in this deposit made in the United States Geological Survey laboratory at Washington. As has been stated, these results are of negative import, so far as a valuable content of potash is concerned.

Potash analyses of samples from Soda Lake, Cal.

[W. B. Hicks, analyst.]

Sample No.[a]	Material.	Soluble portion (ignited).	Potassium in the soluble portion.		
			K.	K_2O.	KCl.
31	Concentrated brine	29.02	0.40	0.49	0.77
34	Bloedite crystals	78.10	.10	.12	.19
35	Salt crust, average sample	89.66	.05	.06	.09
36	Concentrated brine	29.16	.63	.76	1.20
37	do	26.39	.36	.43	.68
38	Salt crust, average sample	88.12	.06	.08	.13
39	Concentrated brine	30.19	.29	.34	.54

[a] For location see fig. 39.

Sample No. 31 was a 1-quart sample of the natural ground-water solution found standing in a 4-foot hole that had previously been dug in the dry-lake flat at a point near the end of the tram track extending out from the soda plant. In this pit clear, transparent, needle-like efflorescent crystals had formed with chilling of the solution overnight. No. 34 was a collection of the isolated crystals afterwards determined as bloedite. No. 35 was an average sample of the surface crust of white salts collected from many places within a radius of 100 to 200 feet near the locality of sample 31. No. 36 was a 1-quart sample of natural ground-water solution from an open pit in the salt crust at the end of the tram line. This is a wet place, said to be about the lowest point in the dry lake and the last point to dry when the whole deposit has been flooded. It is evidently a low point in the channel of the salt, if such a channel exists, although it is situated near the shore on the north side and not in the center of the lake. No. 37 was a 1-quart sample of natural ground water from a pit dug in the dry-lake surface near the tram track and nearer the soda plant than the pit sampled in No. 31. No. 38 was a sample of the surface salt crust made up of many portions collected about the four posts marking the south quarter corner of sec. 12, T. 31 S., R. 19 E. The salt crust was about 2 inches thick at this place. No. 39 was a 10-ounce sample of natural ground water which trickled into a hole dug at the locality of sample 38.

In the foregoing table the figures given in the third column indicate the percentage of the original sample represented by the soluble portion after ignition at low red heat. This eliminates both the waters of the solutions and, in the salt-crust samples, the water of crystallization. The potassium content is expressed in different forms for the convenience of the reader who may have used one or the other form as a basis of comparison, and represents percentages of the soluble ignited residue only and not of the original sample.

Several other pits 2 or 3 feet deep dug in the lake bottom yielded little or no available samples of ground water within half an hour or more. Water was said to have been more plentiful on other occasions when such holes had been dug. The lake bed underlying the surface salt crust was found to be everywhere essentially a fine dark wet mud to the depth examined.

In summary it may be stated that so far as tested the sodium sulphate in the relatively thin saline crust that covers the surface of the dry-lake bottom is all that appears to be available for commercial development. At present the mineral bloedite has no commercial value. The probability of the presence of deeper saline crusts is not considered very strong, but there is, nevertheless, a possibility that such crusts may exist. The available supply of saturated ground waters is believed to be limited to the surficial salt crust. The brine can not be expected to flow readily or replenish itself rapidly through the heavy, difficultly permeable muds in the lake bottom. Free flows, probably of fresher waters, possibly even under artesian head, might be encountered by boring in the lake bottom. Estimating the specific gravity of the salt crust as 1.75 and its average depth as 2 inches over the entire surface area of 2,800 acres would give a gross weight of over a million short tons of crude salts on this deposit, and this is believed to be a warrantable and moderate assumption.

BORATE DEPOSITS IN VENTURA COUNTY, CALIFORNIA.

By Hoyt S. Gale.

INTRODUCTION.

Colemanite, a borate of lime, was first found in Death Valley, Inyo County, Cal., in 1882, and deposits of this mineral were discovered in the following year in San Bernardino County near the old Calico mining district, about 12 miles north of Daggett, Cal. Within the next few years, owing to the use of colemanite as an ore of boric acid and borax, the production of borax from so-called marsh or dry-lake mud deposits ceased, and the price of borax fell to less than 0 cents a pound. The colemanite deposits of Ventura County, Cal., were discovered in 1898, and the district yielded a practically continuous production from 1899 to 1907, inclusive, amounting to a total of about 35,000 tons of crude ore, valued at approximately $1,000,000. After an interval of several years of nonproduction, shipments of ore were resumed during 1911 and there are at present two operating properties in the district.

The borate deposits of Ventura County, although classed among the few important deposits of this class of ores in the country, have suffered the disadvantage of being at a long distance from the main routes of transportation. The district lies in the extreme northeast corner of Ventura County. The deposits are associated with rocks whose outcrop extends in a belt from southwest to northeast from the head of Cuyama River along the southern flank of Mount Pinos, crossing into the southern edge of Kern County along the valley of Cuddy Creek. (See fig. 41.)

The locality is most readily reached from the San Joaquin Valley—for example, from Bakersfield—by the road that runs southward to Lebec and through Tejon Pass. A little over a mile beyond Lebec and less than a mile north of Tejon Pass the road forks and one branch turns westward up the Cuddy Creek valley and thence crosses to Stauffer, in the Lockwood Valley on the headwaters of Piru Creek, a total distance from Bakersfield of about 55 miles. Mail to the mines (Stauffer post office) is brought by stage from Lancaster, on the Southern Pacific Railroad in the Mohave Desert, via Neenach and Tejon Pass, a total distance of about 75 miles. Both of these roads have been used for hauling the borate ores to the railroad for shipment.

The district contains at present three principal "borax" mining properties and a considerable number of other holdings. These properties lie in the foothills at the northern margin of Lockwood Valley, on the headwaters of Piru Creek. They are commonly known as the Frazier mine, property of the Sterling Borax Co., of Los Angeles; the Russell Borate Mining Co.'s mine, belonging to the Russell Bros., of Ventura, and the old Columbus mine, formerly property of the Calm Bros., of Los Angeles, recently reported to have been sold and reorganized under the name National Borax Co. of California. Several

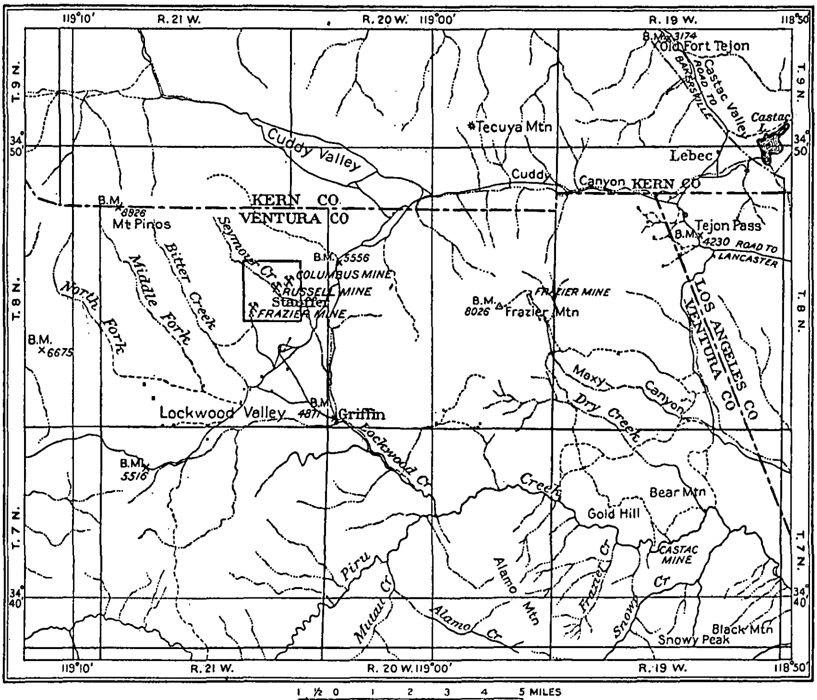


FIGURE 41.—Index map showing borate district of Ventura County, Cal., and the location of the area shown on the sketch map, Plate I.

other properties in the district, largely in the prospective stage, are described in subsequent paragraphs. Some of them have made small shipments of ore.

HISTORY OF THE DISTRICT.

The discovery of colemanite or borate minerals in Ventura County is said to have been made in 1898. Reports state that the material supposed to be "lime" (crystalline calcite) had long been known to prospectors at the present site of the Frazier mine. A prospector named McLaren, who had settled in the vicinity, happening to see some colemanite specimens while on a visit in Los Angeles, recognized that they were identical with material supposed to be lime in Ventura County. Divulging the information thus obtained to acquaintances in Los Angeles, he returned with a party who at once set about locating claims on and near the outcrop then known and later proceeded to develop the property. The first locations were made where crystalline colemanite was visible at the surface of the ground in the steep slope just above the present site of the Frazier mine. Soon afterward other properties were located on adjoining ground. The history of development involves a record of changes in management that is of local and personal interest only.

GEOLOGY OF THE DEPOSITS.

The colemanite deposits occur within a series of bedded rock formations that have been extensively folded and faulted. In general the trend of their outcrop is northeast and southwest and the beds dip southeastward, away from the higher elevations in the Mount Pinos Range. (See general index map, fig. 41.)

A representative section of the formations more directly associated with the borate-bearing beds is exposed in the lower part of the canyon of North Fork, in and near sec. 30, T. 8 N., R. 21 W. Here the stratiform rocks of this series are well exposed in regular section with a uniform steep southerly dip, and the relations of the several members are very clear. From this section, by means of paced traverses along North Fork, the following measurements and general descriptions of the rocks were obtained. This section warrants more detailed study, as the beds are well exposed in the upper canyon slopes.

Stratigraphic section on North Fork west of Stauffer, Cal.

	Feet.
Shale, whitish exposures, containing also beds of light friable sandstone and in the lower part, near the basalt, zones of gypsiferous shale, from which borate minerals, chiefly pandermite, have been extracted. Total thickness not determined, as the upper limit in this section is fixed by a strike fault	300
Basaltic flow rock, with compact as well as vesicular and slaggy layers. The lava flows include zones of shale and in other parts of the field some beds of massive limestone, the latter containing the largest colemanite ore bodies of the field	600
Shale, thin-bedded, at least in part. These beds include zones of much contorted shale whose outcrops are conspicuous for the abundance of gypsum in thin stringer veins which they contain. These gypsiferous zones have been prospected for borate ores	625
Sandstone and conglomerate, white or light-colored, usually forming massive ledge outcrops. Composed mainly of light-colored granitic wash material	150
Shale, light-colored, not conspicuously exposed	200
Conglomerate, dark reddish or iron-stained in general aspect, composed of large bowlders or cobbles consisting of gray and pinkish granite, with fine granitic material. A conspicuous ledge-forming rock	250
Sandstone, white, friable, and shaly beds; not measured, apparently limited by a strike fault.	
	2, 125

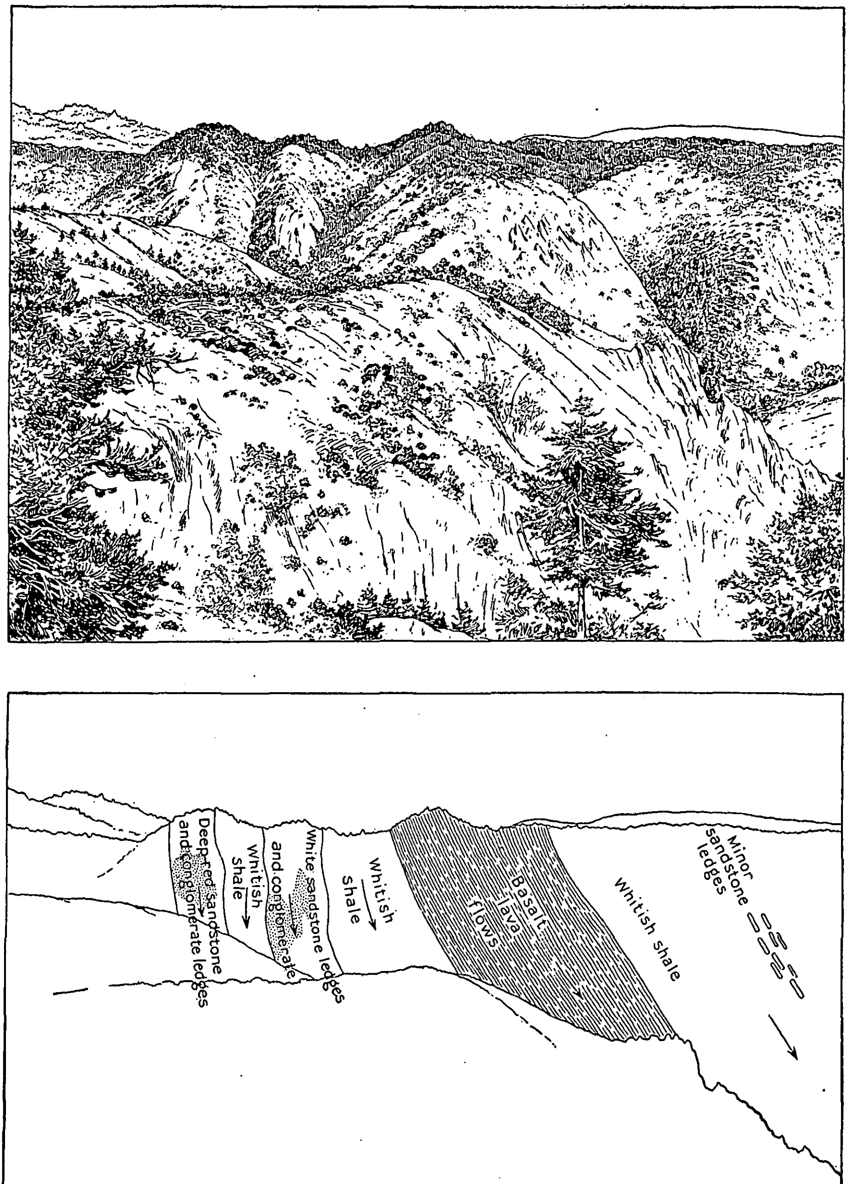


FIGURE 42.—View and section of the borate-bearing beds on North Fork, Ventura County, Cal., looking northeast across the lower cañyon from a point situated on the outcrop of the tilted basalt ledges. Arrows indicate dip of rocks.

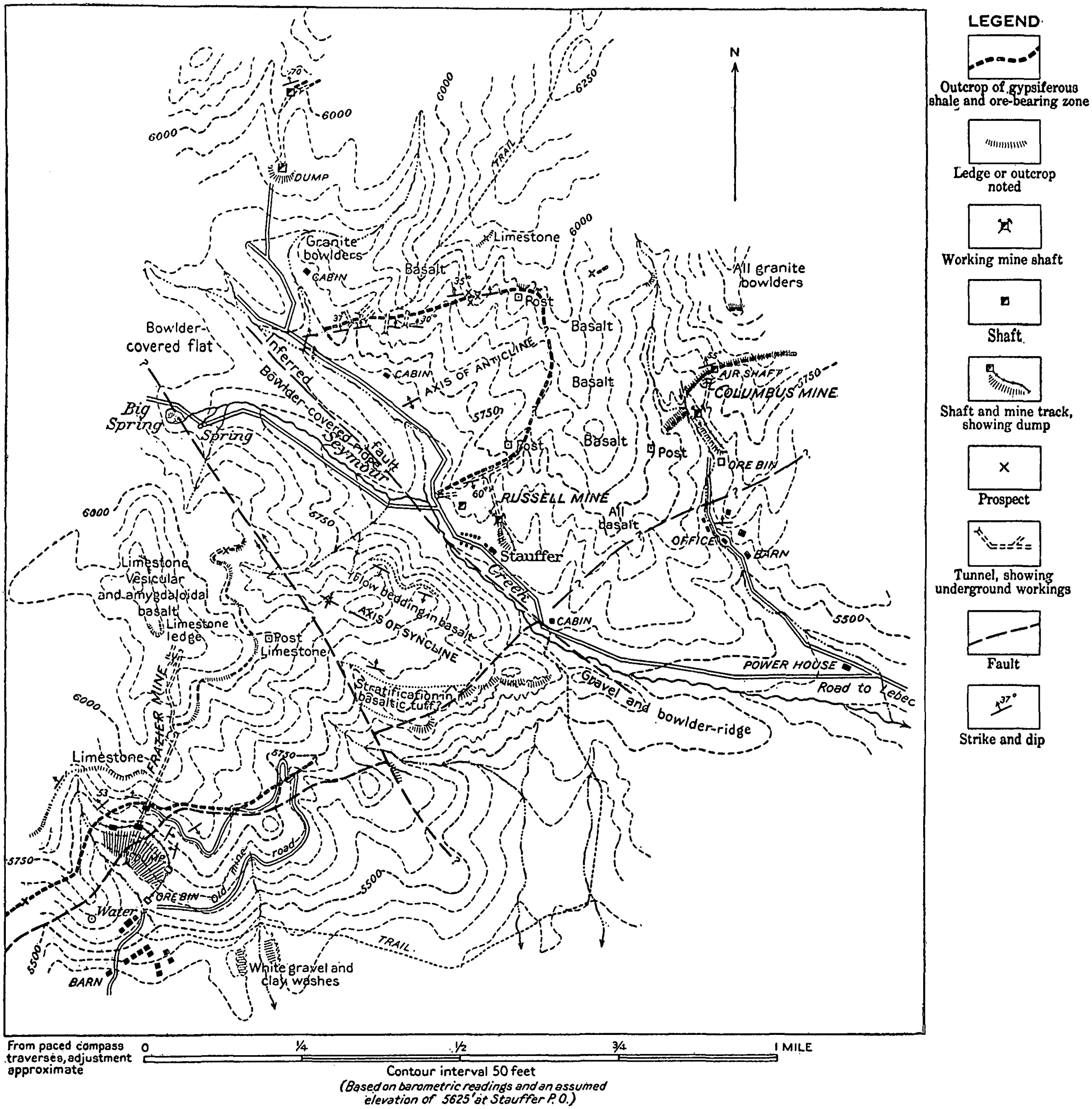
The dip of the whole section is fairly uniform toward the south or southeast, the angles ranging from 70° to 80°.

The view given herewith (fig. 42) illustrates the general aspect of the North Fork section described above, as seen from the summit on the west side of North Fork looking northeast. In a region of less pronounced faulting or other deformation such a section would not be unusual, but it may here be taken as a key to the stratigraphy of the borate deposits. The whole section dips conformably with the basalt flow rock, which is by nature one of the most distinct lithologic units in the series. The basalt and the conglomeratic members form the units more resistant to weathering and erosion, and these stand out as distinct ledge-making rocks, also forming the higher crests or summits along the ridges.

Both north and south of the section described are exposed thick beds of other rocks whose relations, other than that they are generally faulted into juxtaposition with the rocks described, have not been determined. Along the north side of Lockwood Valley are extensive exposures of white clays and gravels, distinctly bedded but only slightly consolidated, whose most distinguishing characteristic lies in the manner of their erosion and exposure. These formations weather or cave into great fluted wash banks, intricate in the detail of pinnacles and large to minute gullies. Small exposures of these wash banks are to be seen just east of the Frazier mine, and larger ones lie in the ridge that projects south into Lockwood Valley between Bitter Creek and Middle Fork. Very extensive exposures of similar character were observed from a distance in the upper part of Dry Canyon, in the headwater region of Cuyama River. These also include strata of white and varicolored clays, which are in a few places exposed in wash banks near the borate deposits, showing hues of red, pink, and pale greenish.

The borate-bearing beds lie in the sedimentary rocks closely associated with the basalt lava flows. Even if a genetic relationship between the borate deposits and the basalt can not be said to have been established, the regional association is borne out by the observed distribution of the deposits. From the detailed descriptions of the colemanite deposits developed in the mines it will be noted that the larger ore bodies have all been found in shale zones which are included within the lava flows, so that the shales were evidently deposited during interflow epochs. Similar shale zones both above and below the lava flows have been extensively prospected for borate ores, and several considerable deposits (chiefly pandermite) have been opened there. In a general consideration of the geology of these deposits attention is therefore chiefly directed to these lava flows.

The outcrops of the basaltic lava flows extend along the foothills of the Mount Pinos Range throughout the district in which the borate



SKETCH MAP OF BORATE DEPOSITS NEAR STAUFFER, VENTURA COUNTY, CAL.

minerals occur. The lavas are essentially continuous throughout the district, although they are in part offset or interrupted by faults and duplicated by folds and faults. They were observed to extend westward from North Fork, probably reaching to and beyond Cuyama River, and they may be traced eastward, with some interruptions where crossed by recent alluvium-filled valleys, down the Cuddy Valley almost to Tejon Pass and possibly beyond.

The basalt (called porphyry at the borate mines) observed in the district is undoubtedly an original surface flow rock. This is attested by its vesicular character as well as its evident flow-bedded structure. The vents through which this lava was extruded are not yet known and no dikes of this rock were recognized with certainty. A coarsely porphyritic dark rock of granular texture, with large phenocrysts of pinkish feldspar, presumed to be intrusive, forms the point of the ridge in the forks of North Fork below the borate properties. This rock and the granite of the Mount Pinos Range are the only igneous rocks, except the basalt, that were found in the immediate vicinity of the borate deposits.

The basalt as exposed on the hill slopes may be described as an obscurely porphyritic rock, bright rusty red in color on the exposed and weathered surfaces. The red color of the outcrop and soil makes it easy to recognize in distinction to the sediments. Layers of flow banding or the bedding of tuffaceous slag show various colors ranging from blackish to a bright red. Many layers are vesicular, proving the extrusive character of the rock. Some of the vesicles, as observed at the crest of the hill above the Frazier mine, are filled with amygdules that are composed in part of natrolite and analcite but contain also more or less abundant quartz and chalcedony. In places, as on the hill east of the Russell mine, chalcedony geodes, derived from cavities in this rock, are scattered about on the surface. The thickness of these flows as determined on North Fork is 600 feet, but it is supposed that, like the shale lenses locally included within them, they vary considerably in thickness from place to place.

The outcrops of the shale zones within the lava flows are distinguished by their lighter color against the dark reddish outcrops of the basalt and the soil derived from it. Massive ledges of limestone occur within these shale zones, particularly at the Frazier, Russell, and Columbus properties, and appear to be intimately associated with the principal ore bodies. These limestones outcrop at some places as massive, rough-weathering ledges.

The rock structures in this district, as throughout this general region, are complex in both folding and faulting. Some of these structures are indicated in detail on the map of the borate deposits (Pl. IX), but even this map is incomplete. References to other details of structure are given in the description of properties. A few of the major features are mentioned below.

The north border of Lockwood Valley is evidently determined by at least one major fault, the relations of which are not yet understood. Another fault of considerable magnitude, approximately parallel to the strike, crosses North Fork about a mile north of the major valley-margin fault.

Some details along the valley-margin fault observed near the borate mines are shown on the map (Pl. IX). From a study of this area it is also evident that there is a system of faults transverse to the valley-margin fault and offsetting it. This relation is very distinct at a point between the Russell and Frazier mines. Smaller faults of this transverse system are found near the Columbus mine, following the lower canyon valley of North Fork and elsewhere.

BORATE ORES.

The valuable borate mineral in the deposits of Ventura County is colemanite, a borate of lime, which may be expressed by the formula $Ca_2B_6O_{11}.5H_2O$, whose theoretical composition is as follows:

B_2O_3	50.9
CaO	27.2
H_2O	21.9
	100.0

Its specific gravity is about 2.4.

Colemanite is a monoclinic crystalline and massive mineral, with uneven fracture, transparent to translucent, with vitreous luster, usually either colorless or milky white. It has one highly perfect and another distinct cleavage. When heated it decrepitates and, losing its water, is reduced to a loose white powder. It is relatively insoluble in water, tests by W. B. Hicks, made at the writer's suggestion, showing that about 1 part in 1,100 of water is taken up at ordinary temperatures (20–25° C.). It is soluble in hot hydrochloric acid and boric acid separates on cooling. This mineral is the principal constituent of the borate ores now mined in the Ventura County district.

Two other mineral forms of borate of lime resemble colemanite so closely in chemical composition that they are not usually distinguished from it by analysis, but differ in physical form. The term pandermite, as applied to California borate minerals, signifies an apparently amorphous compact massive form which does not decrepitate on heating, occurs in the deposits of Ventura County, in places apparently to the exclusion of colemanite. The so-called pandermite is not as readily susceptible to reduction to merchantable forms as the colemanite and it has not generally been considered of value as ore. It is characteristically white, but its chemical composition and mineralogical properties have not yet been studied in detail. The other form of borate of lime near colemanite in composition is priceite, which is massive, friable, and chalky. This mineral has been found at one locality in the United States, on Chetco River, in extreme southwestern Oregon.

A variety of colemanite called neocolemanite has recently been described[1] as being the principal constituent of the borate ores at Lang, Los Angeles County, Cal., a deposit resembling the deposits of Ventura County. The mineral agrees with the colemanite from the Death Valley and Calico districts in its chemical composition, but has somewhat different optical and crystallographic properties.

The colemanite of the deposits of Ventura County occurs in roughly lenticular bodies which are extremely irregular in outline. The greater part of the ore is massive and crystalline, ranging from the transparent glassy crystals occurring here and there to milky-white masses. Most of the deposits are of dark-gray to blackish color, probably owing to included impurities. In general the material would be described as a gray ore.

A variety locally distinguished as "needle ore," while probably not of much practical importance, has attracted some attention. It consists of stringer veins of distinct cross-fibrous structure ("needles") generally formed in thin bands between the evenly bedded shale layers adjacent to the main colemanite ore bodies. A specimen of this ore, analyzed by Maner L. Wade at the Russell mine, showed approximately the normal boric-acid content of colemanite, and it seems likely that this is merely a thin stringer-like form of that mineral.

The mineral masses as a whole are of very irregular form, but they have been generally referred to as bedded deposits, because they appear to follow the bedding of the sedimentary strata with which they are associated. When examined in detail, however, the mineral colemanite does not exhibit any bedding structure, but only the forms characteristic of the crystallization of the mineral itself. The massive deposits are either crystalline without definite arrangement or show radial structures as well as seams of definitely vein-banded material, commonly containing open cavities lined with crystal terminations. The irregularity or bunchy character of the deposits alone would prohibit strict parallelism with the distinctly bedded shales in which they are included. Other evidence afforded by the deposits themselves is suggestive of a vein mode of formation.[2]

The gangue of the colemanite ores in Ventura County is chiefly shale, with some limestone. The limestone is believed to be directly associated with the larger ore bodies. The ore-bearing lodes are evidently zones of brecciation or foliation in these sedimentary rocks. The limestone is shattered and cemented and in part replaced by colemanite. The shale has been crushed and crumpled by movements of the adjacent rocks.

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[1] Eakle, A. S., Neocolemanite, a variety of colemanite, and howlite from Lang, Los Angeles County, Cal.: Bull. Dept. Geology Univ. California, vol. 6, 1911, No. 9.

[2] Gale, H. S., The origin of colemanite deposits: Prof. Paper U. S. Geol. Survey No. 85—A, 1913.

The so-called pandermite is believed to occur in minor quantities in the principal deposits that have been mined in the district, and is in irregular masses where noted. A number of prospects opened in properties on Bitter Creek, Middle Fork, and North Fork are reported to have disclosed large bodies consisting almost exclusively of pandermite. As none of this material seems to have yet been successfully used in the commercial manufacture of borax, work on these deposits has not been continued. It is believed to be generally true, however, that the principal masses of pandermite ore opened outside of the productive mines have been derived from shale zones both above and below the section of basalt flows. A single large cavity in the massive basalt filled solidly with pandermite was observed in the Russell mine, but it is not known that this has any relation to the main ore body.

The outcrop of the colemanite ore-bearing zones may be distinctly traced at least for a certain distance at the Frazier, Russell, and Columbus mines, and as these are the only occurrences of proved ore in depth, inferences concerning change of character in depth must be based largely on these examples. On the Russell and Columbus properties colemanite itself either does not outcrop or shows only in minor amounts. The original outcrop from which the deposits were first discovered occurred at the Frazier mine. This outcrop, however, may be regarded as more or less accidental, for it occurs at the head of a steep slide and is in fact somewhat more in the nature of an artificial exposure. In general, it appears that the colemanite ore has not been found to any extent in outcrop on the surface.

The chief characteristics of the outcrops seem to be the occurrence of gypsum, in stringer form, mainly interlaminated in the bedding of the fissile and crumpled shales, as a rule closely associated with beds of basaltic lava and in the principal ore bodies with ledges of massive travertine-like limestone. A characteristic of the associated shales that is conspicuous in some of the outcrops is the occurrence of small rounded calcareous concretions or "buttons," which are commonly mistaken for fossils.

The gypsiferous shales are very characteristically crumpled in closely compressed folds, which are presumed to be the result of stress on these weakest members of the series at the time the major folding movements were taking place. Such beds naturally afford the open spaces for vein deposition, aside from the influence their calcareous composition may have had in producing precipitation by chemical reaction. The crumpled shales evidently afford zones favorable to the more ready circulation of ground waters.

The presence of massive limestone in the principal ore-bearing zones of the district has suggested another feature of the probable mode of origin of these deposits. Certain specimens of ore and limestone obtained from the mine dumps show indisputably that some of the colemanite is a replacement in the limestone. The similar relation of the larger bodies of colemanite to the thick deposits of limestone is suggested, although substantial evidence on this point is at present not at hand.

The borate mineral has been found in greater or less amounts at numerous places in prospecting on the gypsiferous shales, and it is a common inference that "borax makes only at depth." Just how far to credit this generalization is not yet satisfactorily determined, but the evidence certainly seems to favor the idea. As it is difficult to believe that the deposition of borate ores could have been so recent as to have had any original relation to the present topographic surface, it becomes in a way necessary to consider the possible later migration of the ore material. There may have been leaching of the colemanite at the surface and dissemination or possible redeposition at or near ground-water level or elsewhere, gypsum being brought up by circulation or capillarity of ground-water solutions and deposited by crystallization on the outcrop. This supposition brings in the consideration of possible enrichment of the ore bodies, or merely the complete removal in solution from the outcrop zone without localization of redeposited material.

DETAILED DESCRIPTIONS.

MAPPING.

The accompanying map of the more important developed part of the borate district was prepared by the writer, based on foot-paced compass traverses made during the examination of the property. As it is not the result of precise instrumental work the locations and relative adjustments are not intended to be exact, but in general it is believed to be a good representation of the district. The contours and elevations are based on barometric readings, tied to the elevation of the United States Geological Survey bench-mark post set on the south side of the road in the road gap between Cuddy and Lockwood Valleys, which is marked with the elevation of 5556. The district is shown on the smaller-scale topographic maps of the Mount Pinos and Tejon quadrangles of the United States Geological Survey.

FRAZIER MINE.

The Frazier mine (see Pl. IX) is situated about midway between Seymour and Bitter creeks, the tunnel entrances and mine dumps occupying a steep slope on the front of the foothills of the Mount Pinos Range, overlooking Lockwood Valley. The mine entrances are located near the southwest corner of sec. 14, T. 8 N., R. 21 W.

The Frazier was the first property located for "borax" in the district and has the most extensive underground development.

The property is reported to have been discovered by a prospector named McLaren. The first locations were filed in 1898, and the work of development was undertaken soon afterwards. The mine first reported production in 1899 and continued from that date to and including 1907, since when no ore has been shipped from it. It is estimated that the total amount of crude ore shipped from this property alone has been about 25,000 short tons. The mine and a rather extensive series of claims adjoining are said to be the property of the Sterling Borax Co., of Los Angeles.

The examination of the underground workings of the Frazier mine was not made in sufficient detail to permit anything like a complete description at the present writing. The property was idle and conditions in the old workings were not so favorable for study as in properties more recently worked. The following notes and the course of the tunnel shown on the map (Pl. IX) were obtained on a single rather hasty trip through a part of the mine, without the attempt to make a complete survey or to work out in detail the minor features of the local geology.

The outcrop of the ore-bearing zone at the Frazier mine is represented by a thickness of 40 feet or more of thin-bedded gypsiferous shale, which includes in its midst a ledge of fractured and rough-weathering limestone some 12 feet thick. This section is limited above and below by basalt, being evidently interstratified within the flows of the lava. The shales may be readily traced around the steep hill slopes in both directions from the mine. An overlying zone of shale, also including a limestone ledge, outcrops higher on the slope. These zones of interlaminated sediments within the lava flows are supposed to be of lenticular form and therefore probably not continuous for long distances.

Within the mine the ore body consists chiefly of whitish or grayish crystalline material, essentially massive colemanite. The ore is reported to have been very irregular in thickness, pinching and thickening again as traced by development. It is now evident, however, that good ore still remains at the extreme north end of the present workings. Ore to a height of 5 or 6 feet is still exposed in some of the more recent-looking workings. The greater part of the mine is now so heavily timbered that no estimate of thickness or character of ore could be made.

The uppermost entry in the bluff is reported to have been the first working and to have consisted of a 35-foot incline starting from the outcrop and a nearly horizontal drift for about 70 feet more. This working, which is on the lower of the two outcropping zones of shale and limestone, followed a lens of ore 14 feet thick, from which 1,300 tons of ore is said to have been taken. At a somewhat lower level, opposite the old boiler house at the top of the dump, at the terminus of the wagon road that formerly led up to the mine, is a tunnel reported to have run in on a level for 160 feet, down a slope of 45° for about 280 feet, and beyond again on a level, presumably following the course of the same ore body as that developed by the higher workings.

The main tunnel starts in on a still lower level, from the line of track and snowsheds which cross the head of the main dump. This tunnel presumably strikes the same ore body as the upper workings had reached, and from it the most extensive drifting and stoping have been done. Some of these workings were hastily examined and traversed, as indicated on Plate IX. As shown, the main tunnel extends under the hill in a northerly course for at least a quarter of a mile. For the first 600 to 700 feet from the entrance the main entry is driven through basalt, beyond which the shale underlying the ore body was encountered. When they reached the ore the tunnels were run on almost horizontally along the course of the vein, with numerous branching tunnels and stopes. It is evident that a large amount of ore has been extracted from these workings.

A still lower tunnel situated in the gulch below the main dump was reported as having been driven for the purpose of cutting the limestone "dike" which outcrops with the ore in the slope above and was supposed to have dipped this way. It is said that this tunnel is 1,700 feet long, but that it did not encounter any ore of importance. It seems to have been started in the shale on the south side of the valley-margin fault.

RUSSELL MINE.

The mine of the Russell Borate Mining Co. was the only property in operation at the time of the present examination (October, 1912). The post office, Stauffer, is at the company's store near the mine, situated on Seymour Creek, near the middle of sec. 14, T. 8 N., R. 21 W.

The workings consist of a main shaft that was down 200 feet at the time of this examination, sunk in the basalt, from which a main tunnel has been driven N. 16° W., reaching the ore body at a distance of about 350 feet from the shaft. From this point the mine workings follow the ore body, which has a general trend of approximately N. 75° E., with variable southerly dip, averaging perhaps 60°. A winze sunk in the main entry near the ore body reaches the 250-foot level in the mine, and a considerable amount of ore is developed from that entry. The lava cut at the base of the main shaft is vesicular and is filled with zeolites.

The ore body in the Russell mine is included in a section of shale and limestone interbedded in the basaltic flow rocks, the whole series having a dip of about 60° S. The shales associated with the main ore body are shown by the crosscuts in the mine to be at least 150 feet thick, the north basalt wall not having been reached in any of the developments visited. The ore bodies are very irregularly distributed in the ore-bearing zone, in at least one place apparently showing good ore across a section of about 50 feet. The largest ore bodies, however, including the highest-grade ore, are found along a slickensided or fault-gouge wall encountered at the footwall in the shale, on the north side of the ore body. The gouge is a foliated clay, coaly black and fractured in polished flakes. It includes smooth rolled balls of similar claylike material, probably also indicating movement along a somewhat irregular fissure. Beyond (north of) this footwall, the shale is fine and even grained, containing thin lenses of calcareous shale and some stringer veins or lenses of so-called needle ore, which is supposed to be colemanite, but is not present in sufficient quantity to be of value.

The main ore body consists of glassy crystalline colemanite, mostly massive, varying from white to dark in color, the latter known as the "black" ore. The ore contains a few cavities showing clear glassy, distinctly terminated crystals. Some of the best and most massive ore has a marked spotted or blotchy appearance, especially near the black footwall gouge, where the white crystalline ore is intermingled with patches of dark-gray to black, similarly crystalline ore in a solid mass. The ore is so mingled with limestone that it varies from nearly pure colemanite to limestone masses containing blotches of colemanite. The relation is certainly in part suggestive of replacement of the original calcium carbonate by calcium borate. As a whole the ore bodies are exceedingly irregular, in general form also suggesting the replacement type of deposit. In part, however, the colemanite is undoubtedly original vein matter, as shown by its typical banded vein structure and the fact that it occupies distinct fissures.

A crosscut run south from the 200-foot level of the main shaft traversed mainly basaltic lava for 190 feet, beyond which a second shale band about 10 feet wide was encountered, but this shale contained no ore nor limestone. Near the main shaft along this crosscut a massive vug of clear white material said to be pandermite was observed to be embedded in and completely inclosed by the basalt. It is a chalky white material of uniform grain and rather hard and compact.

Special attention was directed to observation of the occurrence of gypsum at depth in the mine. Gypsum is present in abundance throughout the outcrops of the shale zone which in depth is associated with the ore bodies, and it is generally supposed throughout the field to be the "cap rock" of the ores. At the surface it consists of secondary stringer veins of selenite following bedding or other openings in the shale, and it is thought that this may very likely be a surface phenomenon. Gypsum is to be found on the lower levels of the Russell mine, but, as nearly as could be judged, in nothing like the abundance in which it occurs on the surface. It is believed to be a relatively minor constituent of the vein in depth.

The geologic structure at the Russell mine and in that vicinity is only partly understood. That the mine itself is situated on the south flank of an east-west anticlinal fold of the borate-bearing beds seems satisfactorily determined. The portion of the outcrop that crosses the axis of the fold as shown on the map (Pl. IX) has not been actually traced on the ground. The anticline is indicated by the dips of the strata, the apparent repetition of the large craggy limestone ledges associated with shales, the occurrence of the "button" concretions in the associated shales with the borate beds on both flanks of the fold, and borate minerals showing in the double succession of exposures in Seymour Canyon, which are believed by the writer to be outcrops of the same section of beds. A view from the summit above the Frazier mine west of Seymour Creek, looking east toward the Columbus property in line with the axis of this anticline, shows, in a favorable light, unmistakable evidence of this fold. The axis runs about N. 65° E., and the dips of the north flank are considerably less steep than those on the south, as at the Russell mine. It seems likely that the same folds extend eastward into the gulch in which the Columbus mine is situated, but the axis probably passes considerably north of the Columbus mine. These relations have not, however, been worked out to an entirely satisfactory conclusion.

The rocks exposed in the wooded ridge north of the Seymour Creek anticline suggest a correlative synclinal fold, which would in part account for repetition of the outcrops of borate-bearing shales in the upper part of the Seymour Creek valley.

As shown by the map (Pl. IX) a fault has been postulated following the channel of Seymour Creek. This is not proved, but seems the most reasonable assumption to account for failure to find the outcrop of the Russell ore body across the creek to the west, in direct extension of that part already developed. Furthermore, the structure indicated in the flow beds on the west side of Seymour Creek does not appear to be related to the structure of the east side of the creek, and it is thought that the stream channel itself may be a most likely site of dislocation by faulting. These structures will undoubtedly be m de clearer through the further mining development of the ore bodies.

The ore at the Russell mine is sorted by hand for shipment, yielding a large proportion of very high-grade material. Pure colemanite theoretically contains about 51 per cent of boron trioxide, 27 per cent of calcium oxide, and 22 per cent of water. The ore shipped is said to average 42½ per cent of boron trioxide in the first grade, of which a considerable proportion is obtained, and about 29 per cent in the second grade. The crude ore is sent by wagon to Bakersfield or Lancaster, whence it is shipped by rail to San Francisco for manufacture into boric acid and borax.

OTHER PROSPECTS ON SEYMOUR CREEK.

A considerable amount of prospecting has been done in the upper valley of Seymour Creek above the Russell mine. The gypsiferous shales within the basalt flows outcrop on the north flank of the east-west anticline, of which the Russell mine is assumed to mark the south flank. Several prospect tunnels on the northwest side of the valley in the hill slope 500 or 600 yards northwest of the Russell mine follow a well-defined band of the gypsiferous shales included in the basalt flow beds, and this outcrop is believed to represent the same ore-bearing zone as that worked at the Russell mine. The lowest of these prospects consist of two old entry tunnels in a small gulch or draw, in which the strike of the beds is N. 75°–80° E. and the dip 35°–40° N. The tunnels run in under a massive pitted weathering limestone, similar to that associated with the Russell ore and also with the ore of the Columbus and Frazier mines. At each prospect the basalt is intimately associated with the prospected beds, showing just above the tunnels as well as in the hill slopes below. A considerable amount of vein gypsum is developed in all the shales prospected. Other tunnels, more conspicuous as viewed from the valley below, are situated in the steep hillside east of the two tunnels just mentioned, and conditions in all these tunnels are essentially similar. The small spheroidal concretions which have sometimes been mistaken for fossils are abundant.

Prospecting has been done also north of the open valley, on upper Seymour Creek, in at least one place showing a mass of gypsiferous shale similar to that in which the borate ores occur. It is possible that the basalt and associated borate-bearing shales are here repeated by folding or faulting, or both, and this may explain the further series of outcrops in this part of the valley.

COLUMBUS MINE.

The Columbus mine, which is the northeasternmost of the three principal properties in this district (see Pl. IX), is situated near the middle of the east side of sec. 14, T. 8 N., R. 21 W. The mine is reported to have been located in 1899, the year following that in which the original locations on the Frazier property were made. The locations are said to have been made by B. F. Stevens in the interest of Calm Bros., of Los Angeles, by whose name the property has also been known. The record of production from this mine begins in 1902, reports stating a total production of 8,000 to 9,000 tons of crude ore to 1907, inclusive, after which the property was closed down. The property is reported to have been sold in the spring of 1912 to the National Borax Co., organized to reopen the mine and develop it and the adjoining property. An extensive plant was in process of construction and installation at the time of visit, in October, 1912, including an independent electric power plant using crude oil as fuel, to be obtained from the pipe line at Lebec. A large rotary roaster already on the ground was being refitted, and a new shaft was being sunk from which to reopen the mine.

The underground workings of the old Columbus mine are said to have been extensive, but were wholly inaccessible at the time the property was visited. The main entry of the old workings consisted of a tunnel running in N. 6° E. for 200 feet or more, crosscutting through basalt to the gypsiferous shale and limestone, including some colemanite on this level. Stringer veins of so-called needle ore (see p. 10) were pointed out in the shales of the main tunnel level. These thin seams are reported to consist of high-grade ore, but it is believed that the ore has not been obtained in considerable quantity. The main workings of the old mine were developed through a winze sunk in this tunnel at the shale contact, and the lower levels had filled with water when the mine was abandoned. The ore at the Columbus mine is said to have come almost altogether from the lower workings, bearing out the idea that here, as at the Russell property, borate minerals "make" at depth only. The contact of the basalt and the shale and limestone shows distinctly at the upper end of the winze in the entrance level of this old tunnel, and there is a narrow zone of alteration in the sediments at the contact. It was not proved whether this metamorphism was caused by the heat of the volcanic rock or by secondary alteration along the contact.

The ore body of the Columbus mine is associated with the massive limestone that outcrops in the gulch just above the mine. This ledge strikes north of east and stands nearly vertical. At the outcrop it is about 10 feet thick, and the softer shales are concealed in slide at the base of the steep slope. However, the outcrop of these shales and limestones may be readily followed eastward in the line of strike at least as far as the crest of the ridge above the mine. About halfway up the slope along the outcrop is an air shaft extending up from the old workings, and 30 or 40 feet below this shaft there is another old prospect tunnel. At this upper tunnel the thickness of the interbedded gypsiferous shales included between the steeply dipping lava flow rocks was shown by paced measurements to be at least 100 feet. About 60 feet of this thickness is represented by the beds crosscut at an angle in this tunnel. These beds consist of shale carrying a large amount of gypsum in the form of interlaminated veins of selenite, but no colemanite was noted. Much of the shale is highly contorted. The strike of the beds in the tunnel at the air shaft is N. 70° E. and the dip 55° N.

The structure of the formations in the bottom of the gulch above the Columbus mine is obscure, and the relations are not yet clearly understood, presumably because insufficient time was available for thorough investigation on this property. It appears that the anticlinal axis recognized in the structure on the Seymour Creek side of the ridge should cross the upper gulch of the Columbus property and that the axis would lie 900 feet or more northwest of the Columbus shaft if it is in regular continuation. However, the minor cross faults encountered in the Columbus mine suggests the possibility of considerable offsets in the structure, although it appears more than likely that the continuation of the fold could be traced. Such a fold is suggested by the broad exposure across the strike of the basalt beds and the repetition of gypsiferous shale bands on the property. A more complete understanding of these relationships may prove of considerable importance in the future development of the ore bodies on this property, as well as elsewhere in the district.

The workings on the Eureka claim, about half a mile northeast of the Columbus mine, forming a part of the Columbus property, consisted of a tunnel running in near the summit of the ridge. This tunnel reached a total length of about 120 feet, but remained at shallow depth from the surface, following the strike of the gypsiferous shales, which outcrop conspicuously at this place. The strike in these beds is about N. 45° E. and the dip about 70° NW. The abundance of gypsum on the surface at this place has been taken by the owners of the property as a favorable indication of ore in depth. The gypsum showed in considerably greater amount at the surface and near the tunnel entrance than underground in the tunnel, but no colemanite was observed in either place. The gypsum is evidently a secondary vein product deposited in the bedding planes of the shale, which afford spaces favorable to the deposition of thin veins, but it also fills joints or fissures transverse to the bedding.

BITTER CREEK.

Gypsiferous shales interstratified with basaltic lava flows are abundantly exposed in the lower part of the canyon of Bitter Creek, the first considerable stream west of the Frazier mine. The exposures are supposed to be due to repetition by folding in the beds, as the structure of this part of the district is understood only in a general way. J. M. Fraser, one of the early residents of the district, states that he mined about 40 tons of ore from one deposit that outcropped on Bitter Creek. In all, about 140 tons of ore is said to have been taken out. All these workings have caved and without further development afford at present but little evidence from which to judge the character of the deposits.

When the canyon is entered from Lockwood Valley by way of the old wood road, the basaltic lava flows are crossed in section, with downstream (southeastward) dip as intersected by the stream valley. The thickness of these lava beds is judged to be about the same as on North Creek, possibly somewhat more than 600 feet. Underlying this section is a small showing of the coarse granite-bowlder conglomerate. Beyond this, presumably brought down by a fault, is exposed a contorted section of the gypsiferous shales, whose general attitude must be approximately horizontal, as the exposure of the section follows the grade of the creek for a considerable distance. In detail, however, the gypsiferous shales seem to have dips in all directions. One good exposure in the creek bed strikes N. 30° W. and dips about 45° SW., while the bluff above on the east side appears to be an anticlinal fold with axis transverse to the course of the creek. These shales have been prospected in many places. They are supposed to be the shales underlying the basaltic lava flows, as this rock does not show in the sections. The shale banks weather to yellowish earthy slides. The gypsiferous shales can be traced upstream to the northwest, showing various dips until the lava is again observed on the west side of the creek, evidently overlying the section conformably. This relation continues for some distance until the contortions in the gypsiferous shale increase to an extreme degree, and finally the whole sequence breaks off with a sharp tilting up of all the beds against the exposures of underlying strata on the upstream side. These underlying strata include some soft whitish sandstone. A huge block of granite-bowlder conglomerate or breccia is exposed on the west side of the gulch, which may be a portion of the outcrop of the similar formation that underlies the basalt and shale in the North Fork section. Beyond this the stratigraphic relations are obscured in the fluviatile débris that has been washed down through the rugged canyon by which Bitter Creek emerges from the higher mountains. It is possible that the Bitter Creek canyon represents also a line of transverse (northwest-southeast) faulting. The general anticlinal structure exhibited in the contorted gypsiferous shales is interpreted as a continuation of the anticlinal structure shown in the mountain above and north of the Frazier mine. This structure is supposed to be continuous westward across Middle Fork, with modified form to be discussed with the rest of that section.

DEPOSITS OF MIDDLE FORK.

Middle Fork, or Center Creek, as this stream is locally called, affords an interesting section, including the borate-bearing beds, in structures which are believed to be somewhat more readily interpreted than those farther northeast. This section lies between the camp of Mrs. S. D. Ives, situated at the mouth of the canyon, near the southwest corner of sec. 21, and the little falls not quite a mile above the camp.

The borate-bearing beds and lava are repeated by faults on Middle Fork, a lower belt of these beds outcropping on the face of the bluff at the mouth of the canyon and the beds again crossing the course of the stream higher in the canyon at a point just below the rocky gorge and little falls above referred to.

The lower part of the Middle Fork canyon is cut in nearly horizontal, massively bedded sandstone and pebble and bowlder conglomerate. To the south, or toward the valley at the canyon mouth, these beds apparently dip southward, and it is assumed that they terminate in the same valley-margin fault that is exhibited near the Frazier and Russell mines. These are the beds underlying the series comprising the borate-bearing shale and basalt lava flows. Upstream these horizontally disposed beds are terminated by a fault transverse to the course of the valley, which is supposed to be in more or less direct extension of the general anticlinal structure lying above and north of the Frazier mine. On Middle Fork this fault terminates the section of horizontal structure and the borate and lava series is repeated in steeply tilted rocks above. In the upper part of this canyon the prospects for borates are in the shales underlying the lava beds instead of being in shale layers included within the flows themselves. Pandermite is shown in a pile of slabs at an old pit in the upper section near the creek, but no ore has ever been shipped from this place. It is believed that the work was done as assessment work on claims and has not been carried to any great depth. The Ives tunnel, high on the hill slope on the west side of the creek, was being driven at the time of visit, but the work had not advanced far enough to give much of a cross section of the borate shales, being in the beds below the lava and not having extended in as far as the base of the flows. The tunnel had been driven in toward the south for a distance of 50 feet. The strike at the breast of the Ives tunnel was N. 70° E. and the dip 50° S. Stringers of gypsum, which are abundant on the surface croppings of the shale, show in much less amounts interlaminated with and filling cross fractures in the shale at the breast of the tunnel. They have a maximum thickness of about an inch. Just below the mouth of the tunnel and the outcrop of gypsiferous shales is a great exposure of the granite-bowlder conglomerate, at first sight suggesting a fault relation, but very probably underlying the shale in normal sequence. It is this ledge which, being cut by the stream channel, produces the picturesque little falls already referred to.

The following section, partly measured, partly estimated, was taken from the steeply dipping shales of upper Middle Fork:

Section of borate-bearing beds exposed in Middle Fork canyon.

	Feet.
Interval, probably shaly, covered by slide. This is the south or downstream end, and begins with the stratigraphically younger beds at the top; beyond (downstream) are exposed the flat-lying shales and vesicular basalt at the margin of the creek, but this exposure is supposed to be due to a surface slump	30
Shale, gypsiferous, thin bedded	90
Shale and some sandstone, thick and thin bedded	26
Shale, gypsiferous, thin bedded, rusty	2
Mostly shale, with sandstone layers	30
Sandstone	1½
Shale and sandstone interbedded	15
Sandstone	3
Shale, reddish	18
Sandstone, stratum thin bedded, reddish	1
Shale, thin bedded	12
Interval, covered	9
Sandstone, friable, even grained, thick bedded	12
Shale, brownish	2½
Sandstone, reddish	5
	250

This section represents a portion of the 625-foot interval described in the general section given on page 5 as predominantly shaly beds, underlying the basaltic lava flows. Below this section (downstream) is a highly contorted section of the gypsiferous shales, and on the southwest side of the canyon the steep, rugged slope reveals mainly basalt with interbedded layers of similar shales. No limestone was observed in any of the beds at this locality.

A property known as the Stubblefield & Halloway, situated on the front of the mountain, facing the valley, half a mile or so west of the Ives camp, is reported to have shipped two carloads of ore. The old tunnel had been abandoned at the time of the writer's visit and the property was not examined in detail. The workings consisted of several tunnels, run in on the outcrop of gypsiferous shales, intimately associated with the basaltic lava. The strike of the beds at the entrance to the lower tunnel is about N. 65° E. and the dip is steep, nearly vertical. The general dip here is evidently to the southeast. About 200 yards north of these entries up the gulch the underlying sandstones are exposed in prominent ledges. These make the abrupt flank of the mountain front at this place.

DEPOSITS OF NORTH FORK.

Some prospecting for borate ores has been done on the canyon of North Creek or on the adjoining hillsides. It is reported that about 160 tons of ore have been shipped from a deposit on the west side of the creek, this being principally the work done in obtaining patent to the property. The prospecting here has been confined to either the beds that normally underlie or those that overlie the lava, and no deposits interstratified with the lava flows have been opened. The lava itself, being tilted at a steep angle and exposed in a somewhat regular section, is revealed as a very distinct stratigraphic unit. It seems to be thinner than the aggregate of flows represented in the Frazier, Russell, and Columbus properties. Certainly the shale members interbedded with the flows, if such are present in the North Fork section, are not conspicuous. The prospects along the creek are in gypsiferous shale underlying the lava flows, but reports state that the ore shipped was obtained from similar shales overlying the lava (on the south). There is said to have been developed a very large body of pandermite in shafts high on the hill slope on the west side of the canyon not far from the summit. A shipment of this pandermite as a possible ore of borax and boric acid is said to have been made as an experiment, the material having been taken to Chicago for treatment, where the attempts to utilize it are supposed to have resulted in unfavorable results.

The valley of North Fork in the northern part of sec. 30, T. 8 N., R. 21 W., which is the locality of the section given on page 5, follows the trace of an obvious fault, whose trend is N. 15° W., nearly in the channel of the stream. The fault itself is therefore chiefly concealed in alluvial wash, but the offset in the formations is quite unmistakable. The offset is to the north on the east side or to the south on the west and amounts to several hundred feet at least, no more than an estimate having been made of the horizontal distance. This fault is of the same type and direction of movement as the other faults transverse to the trend of the formations, such as those mapped at the Russell and Columbus properties, and is assumed to be one of a system of such faults occurring in the district.

IVES PROPERTY AND PROBABLE WESTWARD EXTENSION.

The same stratigraphic sequence, including the gypsiferous shales and lava flows, trends in outcrop westward from North Creek for an undetermined distance. Views in that direction from the vicinity of the high point marked "B. M. 6675" on the Mount Pinos topographic map indicate that these formations continue in apparently regular structure almost due west from that point at least as far as Dry Canyon, one of the extreme headwater channels of Cuyama River.

The presence and character of borate minerals within this district remain as yet unproved. A certain tract adjacent to North Fork on the west, extending nearly to the 6,675-foot summit above mentioned, is located in mining claims which follow the gypsiferous shales. This tract, together with some tracts on upper Middle Fork, is known as the Ives property. It extends along the north side of secs. 25 and 26, T. 8 N., R. 22 W.

Here the whole series of bedded formations has a regular east-west trend, with steep dip tending to the south. The excellent views across country from this place make clear the stratigraphic relations and sequence. In a view eastward across North Fork the prominent ledges show the section illustrated in figure 42 (p. 437).

Several shallow pits have been dug on the Ives property west of North Fork. One prospect near the northwest corner of sec. 25, a pit dug at the summit of the ridge, shows a strong development of vein gypsum interlaminated with thin fissile shales, striking east and west and standing nearly vertical. The tilted lava flows show in section from the summit of this ridge down the south slope, so that this prospect is probably in the shale underlying these flows.

East of the prospect just described, on the summit of the ridge, a large bowlder of supposed pandermite had been found lying entirely within the basalt. Some prospecting had revealed nothing further than the basalt, of which the whole crest of the ridge at this place is composed.

No estimate of the value of the property west of North Creek can yet be made. The stratigraphic and structural relations are apparently similar to those of the more completely developed parts of the district. The presence of some pandermite and the outcrops of abundant gypsiferous shale may possibly be indications of ore in depth, but it is safe to postpone any definite judgment until actual conditions shall have been shown by further underground developments.

CUDDY PROSPECTS AND PROBABLE EASTWARD EXTENSION.

The eastward extension of the borate-bearing beds has not been traced in detail. Some very general assertions are to be heard in local statements to the effect that the same belt, including outcrops of shale and basalt, can be traced eastward through Tejon Pass, directly through the producing borate properties at Lang, in Los Angeles County, and beyond.

In crossing from Lockwood Valley northeastward into Cuddy Valley the basalt flows are to be found in outcrop at intervals, following the same general alignment of outcrop as that in the present productive district. The basalt shows in a little knob just west of the old Cuddy ranch in sec. 5, T. 8 N., R. 20 W. Eastward from the

Cuddy ranch the whole section is evidently concealed in the valley wash for a short distance. The trace of the San Andreas rift follows the main Cuddy Valley, and the rocks north of this fault are quite distinct in character from those exposed to the south. Apparently the basalt flows and associated strata assume an eastward trend along the lower Cuddy Valley, for they are exposed again on the south side of the canyon at the foot of Frazier Mountain, in secs. 34 and 35, T. 9 N., R. 20 W., in Kern County, just north of the county boundary line. A prominent foothill peak, apparently composed chiefly of basalt flows folded in anticlinal structure, has been prospected by pits and tunnels in many places. These are known as the Cuddy Bros.' prospects. They were not examined in detail, but it is understood that no ore has been shipped from the locality. Further data bearing directly on the eastward continuation of this series has not yet been obtained.

POTASH IN WESTERN SALINE DEPOSITS.

By James H. Hance.

FIELD WORK.

In 1912 the writer, under the general supervision of Hoyt S. Gale, visited various saline lakes, marshes, flats, and wells, chiefly in the western arid region, for the purpose of sampling and testing their waters and deposits for soluble potassium salts. A cursory examination was made at a number of widely scattered localities, but sufficient time for detailed study was afforded at none of the districts, and the results sought and obtained were chiefly the analyses of samples and a few observations incidental to their collection. Consequently the following is largely a review of the analytical results:

The places visited were Railroad Valley, Fourmile Flat, and Dixie Valley, in Nevada; the alkali lakes near Alliance, in northwestern Nebraska; Estancia Valley, Crater Salt Lake, Playas, and Carlsbad, in New Mexico; Adamana and Cochise Flat, in Arizona. The time devoted to any one locality varied from a day or two to a month, the latter period being given to the alkali lakes in western Nebraska.

NEVADA.

RAILROAD VALLEY.

Railroad Valley is the accumulation basin of one of the larger interior drainage systems of south-central Nevada. It lies about 100 miles east to northeast of Tonopah and a somewhat shorter distance southwest of Ely. Its name is probably derived from the fact that a proposed railroad route (Ely-Goldfield Railroad), which, however, was never carried beyond the making of preliminary surveys, traverses a considerable portion of it. It may be reached by road from either Tonopah or Ely, these being the nearest railroad points.

The valley proper is a typical Nevada desert basin, extending in a general north-south direction for about 85 miles and having a maximum width of 15 miles. Tributary to this valley are several small streams, some of which hold perennial waters in their upper courses, but all of which are generally dry before they reach the valley bottom. Duckwater and Currant creeks flow into its northern end; and the extensive desert valley of lower Hot Creek is tributary to it through the low Twin Springs Pass between the Pancake and Reveille ranges.

Railroad Valley is lowest in its north-central part, where a mud plain, known as Butterfield Marsh, covers an area of approximately 35 or 40 square miles in Tps. 8 and 9 N., R. 56 E. This is a typical mud playa deposit, usually dry though occasionally flooded by storm waters. The mud surface bears a thin crust of salts, especially after flooding and evaporation, but these salts are not prominent and are largely obscured by sediment and wind-swept dust. The margins of the mud flat show salt deposits in more conspicuous form. At the north end of the marsh lies a series of so-called salt pans, irregular areas more heavily crusted with salts and ranging in size from a fraction of an acre to several times that area. These pans are devoid of vegetation and are covered by saline efflorescences several inches in thickness. They stand somewhat above the elevation of the main playa and in time of extreme high waters are flooded and drained to the Butterfield Marsh.

Salt from the pans at the north end of Butterfield Marsh has for many years been collected for local use. In the early days these salts were scraped up into piles and taken to Tybo, a mining camp about 45 miles to the southwest on the west side of Hot Creek Valley, for chlorination of the lead-silver ores. It is reported that the high content of potash in this salt finally led to its disuse and to the substitution of salt from Great Salt Lake. The private investigation of potash prospects in Railroad Valley was suggested by an account of these circumstances found in the company records. Samples of the saline efflorescences tested by the Geological Survey were found to contain as high as 12 per cent K_2O in the soluble portion.

A series of samples, collected by E. E. Free of the Bureau of Soils and the writer, were analyzed by A. E. Merz in the cooperative laboratory at Reno, Nev. In the following tables the results of these analyses have been grouped as follows: Saline residues, including efflorescences and crusts; brines from shallow pits dug in the salt pans north of the marsh; spring and well waters, the average saline content of which is within the limits set for potable waters.

Potash analyses of saline residues from drainage basin of Railroad Valley.

No.	Source of sample.	Soluble portion expressed as per cent of sample.	K_2O content expressed as per cent of soluble portion.
1	Butterfield Marsh	33.86	9.06
2	.....do	44.08	9.87
3	.....do	55.20	12.19
4	.....do	49.10	10.02
5	.....do	58.32	7.18
6	.....do	48.82	11.03
7	.....do	42.62	8.46
26	Crust in center of Hot Creek valley	2.07	5.25

Potash analyses of saline residues from drainage basin of Railroad Valley—Continued.

No.	Source of sample.	Soluble portion expressed as per cent of sample.	K_2O content expressed as per cent of soluble portion.
28	Flat at west end of Twin Springs Pass	13.16	4.25
30	....do	6.22	6.52
40	Crust from east end of Twin Springs Pass	1.74	8.81
43	Crust at Mormon Well	4.55	5.29
45	Crust below terrace at Sharp's ranch	27.36	5.05
48	Crust from flat near Sharp's ranch	33.98	3.10
54	Playa below Willow Springs	25.24	.89
55	Half mile north of sample 54	22.74	3.28
56	Edge of main flat below Bullwhacker Springs	53.80	1.22
57	Main flat one-quarter mile west of sample 56	7.58	1.64
58	Crust from outflow of Willow Springs	33.00	5.87
59	Crust from surface near Bacon Springs	27.56	4.10
62	Crust from surface near Cold Spring	24.48	4.68
64	Surface crust one-half mile east of Duckwater	27.56	1.05
66	Crust from ditch at Irwin ranch	12.10	1.65
71	Surface crust at Locke's ranch	59.92	4.35
75	Crust 6 miles south of Locke's ranch	1.59	....
76	Crust 100 yards southeast of sample 75	4.55	8.53
80	Crust from draw 3.8 miles northeast from Locke's ranch	68.22	6.85
81	....do	56.63	2.98
82	....do	55.72	3.67
84	Crust from dune 5.5 miles northeast from Locke's ranch	14.69	4.06
87	Crust from road 6 miles northeast from Locke's ranch	30.46	4.53
88	Crust from road 6.5 miles northeast from Locke's ranch	24.03	2.33
89	West of west edge of salt pan about 7 miles northeast from Locke's ranch	25.58	5.71
90	West edge of salt pan (89)	49.48	7.91
91	Center of same pan (89)	70.97	6.97
92	....do	74.72	8.46
93	East edge of same pan (89)	56.37	7.54
94	East of east edge of same pan (89)	16.68	3.98
95	Draw 7.1 miles northeast of Locke's ranch	53.00	7.39
96	....do	71.64	9.20
97	....do	69.12	7.72
98	....do	55.16	9.22
99	530 feet east of 95	64.96	8.52
100	....do	66.62	5.76
101	West edge of salt pan 1,100 feet east of 95	34.48	2.22
102	Center of salt pan 1,100 feet east of 95	55.18	8.96
103	....do	43.24	3.90
104	East edge of same pan 1,600 feet east of 95	53.96	3.78
105	Northwest edge of salt flat 0.6 mile east of 95	72.64	6.38
106	100 feet east of 105	46.38	6.73
107	80 feet east of 106	76.38	5.00
108	80 feet east of 107	60.02	3.41
109	110 feet east of 108	58.72	2.38
110	East edge of pan 125 feet east of 109	28.54	3.90
111	Drainage line west of drilling camp, about one-eighth mile east of 110	59.62	6.11
112	125 feet east of 111	59.16	5.45
113	100 feet east of 112	56.48	6.20
114	420 feet east of 113	72.22	4.23
115	Northeast side of salt flat, 6 miles south of Locke's ranch	41.24	1.53
116	One-quarter mile southwest of 115	10.56	6.02
120	One-half mile north of 116	5.36	6.16
122	Below sample 120	79.56	12.10
124	97 feet west of north quarter corner of sec. 2, T. 8 N., R. 56 E	68.74	1.90
125	375 feet west of north quarter corner of sec. 2, T. 8 N., R. 56 E	45.42	2.94
126	725 feet west of north quarter corner of sec. 2, T. 8 N., R. 56 E	56.90	5.04
127	775 feet west of north quarter corner of sec. 2, T. 8 N., R. 56 E	76.40	3.68
128	850 feet west of north quarter corner of sec. 2, T. 8 N., R. 56 E	62.08	6.65
129	1,075 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	55.22	2.73
131	1,350 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	83.40	4.53
132	1,750 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	40.42	2.06
135	1,200 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	68.64	3.39
137	2,225 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	14.18	1.81
139	900 feet northwest of center of sec. 2, T. 8 N., R. 56 E	47.18	1.30
144	1,680 feet northwest of center of sec. 2, T. 8 N., R. 56 E	82.46	2.66
145	Old salt mound about center of sec. 5, T. 8 N., R. 57 E	41.34	2.83
146	1,375 feet northwest of center of sec. 2, T. 8 N., R. 56 E	72.06	2.26
148	Probably west side of sec. 1, T. 8 N., R. 56 E	58.22	9.26
149	100 feet north of 148	44.22	6.58
152	150 feet north of northeast corner of sec. 2, T. 8 N., R. 56 E	29.80	4.83
155	350 feet northwest of northeast corner of sec. 2, T. 8 N., R. 56 E	69.00	10.17
159	1,650 feet southwest of McDonald Spring	67.92	3.79
162	750 feet southwest of McDonald Spring	48.92	1.48
165	1,600 feet southwest of McDonald Spring	64.62	3.26
166	1,200 feet southwest of McDonald Spring	76.58	3.42
168	About 4 miles northeast of Locke's ranch	41.10	1.83
	Average of 85 samples	45.57	5.23

Potash analyses of brines from shallow pits in salt pans north and northwest of Butterfield Marsh, in Railroad Valley.

No.	Source of sample.	Dissolved salts (dried at 105° C.) expressed in grams per 100 cubic centimeters of original sample.	K_2O content expressed as per cent of dissolved salts.
130	Shallow pit 1,250 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	20.87	8.54
133	Upper brine, shallow pit 1,150 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	12.63	6.14
134	Lower brine, shallow pit 1,150 feet south of north quarter corner of sec. 2, T. 8 N., R. 56 E	13.04	6.23
138	Shallow pit near center of sec. 2, T. 8 N., R. 56 E	.97	1.16
143	Shallow auger hole 1,375 feet northwest of center of sec. 2, T. 8 N., R. 56 E	15.74	5.94
153	Upper brine, shallow pit 675 feet north of the northeast corner of sec. 2, T. 8 N., R. 56 E	11.62	11.92
154	Lower brine, shallow pit 675 feet north of the northeast corner of sec. 2, T. 8 N., R. 56 E	12.09	11.78
156	Shallow hole, 300 feet northwest of the northeast corner of sec. 2, T. 8 N., R. 56 E	7.86	11.46
158	Shallow pit, 2,000 feet southwest of McDonald Spring	12.82	5.03
163	Lower brine, shallow pit 2,000 feet southwest of McDonald Spring	13.99	5.49
164	Shallow pit, 1,300 feet southwest of McDonald Spring	13.97	5.82
	Average of 11 samples	12.33	7.23

Analyses of natural spring and well waters from drainage basin of Railroad Valley.

No.	Source of sample.	Dissolved salts (dried at 105° C.) expressed in grams per 100 cubic centimeters of original sample.
17	Currant Creek at Currant post office	0.04
18	Ditch in Hot Creek Canyon at Wagner ranch	.06
21	Spring in Rattlesnake Canyon	.04
23	Stream in Tybo Canyon	.03
25	Draw in center of Hot Creek valley	.07
27	South ditch at west end of Twin Springs Pass	.04
29	North ditch at west end of Twin Springs Pass	.08
31	Spring at house in Twin Springs Pass	.03
42	Mormon Well	.03
47	The main spring, Sharp's ranch	.04
49	Well at Sharp's ranch	.04
50	Willow Springs	.05
51	Standing water on flat below Willow Springs	.18
52	Bullwhacker Springs	.04
53	Standing water on flat from Bullwhacker Springs	.34
61	Cold Spring, 1 mile north of Horton's ranch	.04
63	Draw, 2 miles out of Allred on Duckwater Road	.03
65	Ditch at Irwin ranch	.04
70	Main spring at Locke's ranch	.04
73	Spring 6 miles south of Locke's ranch	.07
157	McDonald Spring	.08
167	Well at drilling camp	.07
171	Black Rock Springs	.04
175	Hot Creek	.07
176	Hot Springs in Hot Creek Canyon	.08
177	Ditch above Hot Springs in Hot Creek Canyon	.05
178	Warm Springs, Hot Creek Valley	.08
186	Warm Springs, near Locke's ranch	.05
187	Well at Blue Eagle ranch	.05
188	Cold Spring at Blue Eagle ranch	.05
189	Warm Spring at Blue Eagle ranch	.04
	Average of 31 samples	.064

The general physiographic evidence in the valley shows that its lowest part has been at some time occupied by a lake. Terraces marking the more permanent of the higher water stages are quite prominent at certain places on the lower slopes, especially on the east side of the valley, above and south of the Blue Eagle ranch. The height of these terraces was estimated as 300 to 400 feet above the lower portion of the valley. A gravel bar, evidence of water action at a lower level, extends into the valley from the mouth of Currant Creek. None of these are of a permanent order but are built of loose and little consolidated material. Their character suggests comparative recency of formation and possibly limited duration of high-water conditions. It is supposed that the lake or lakes that occupied this basin may have been contemporaneous with the Quaternary Lakes Bonneville and Lahontan of this general region.

The hypothesis of the existence of buried saline deposits in this basin, on the basis of which a considerable amount of prospecting in Railroad Valley has already been done, has been reviewed in some detail in prospectuses issued at Tonopah by the Railroad Valley Co.,[1] by whom the work has been done.

In Free's paper the log of a well in Railroad Valley which reached a depth of 1,204 feet is quoted, and its interpretation with reference to possible former lake deposits is discussed. Free concludes that the well record indicates deposits formed in a shallow fluctuating lake, the clay beds corresponding to periods of lake expansion, and the sands and gravels to periods when a contracting shore line had exposed the site or had brought it within the zone of wave-moved sands along the shore. According to Free—

> Specimens of the lime-cemented sands at 1,140 to 1,175 feet have received very careful chemical and microscopical examination, and there seems no reasonable doubt that the cementing material of these strata was deposited on the bottom of an evaporating lake. The occurrence of gaylussite at 1,140 feet is especially significant, since this mineral is not known to be deposited except from waters which are brackish or saline.

It is stated in substance that materials resembling the calcareous tufas of the Lahontan basin and elsewhere have been obtained near the bottom of the well and are considered proof of the existence of an ancient lake whose shores or bottom stood at about this horizon. It is supposed by Free that the well is situated too near the margin of such a former lake to have penetrated any saline deposits that may have been deposited therein.

To Mr. Gale and the writer it appears that the record of lake history as observed in the terraces and gravel bar in Railroad Valley indicates

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[1] Railroad Valley Saline Co.: Potash, Sept. 7, 1911.
Free, E. E., Potash, Aug. 22, 1912; idem, rev. ed., Nov. 25, 1912.
Chandler, A. E., Railroad Valley water supply, Aug. 12, 1912.
Marean, H. W., Railroad Valley soils, Aug. 10, 1912.
Several minor circulars were also issued by the Railroad Valley Co.

a water stage of comparatively recent though prehistoric time. Lack of deformation by erosion of the unconsolidated materials along the existing shore terraces and their general relation to the configuration of the present valley bottom seem to indicate that they belong to a topography not greatly different from that of the present day. If so, the record of the desiccation of the lake or lakes of this period probably does not lie deep in the present deposits of the Butterfield Marsh, and might be recorded at a depth of 100 to 200 feet. It is possible that a stratum of tough white clay shown in the well record as extending from 135 to 187 feet may represent a deep-water stage of this lake. As to the existence of preceding and deeper lakes the present physiographic record seems very inconclusive. Deep well logs may throw the desired light on the subject. On the whole, drilling for potash in Railroad Valley is very much on the same footing as that conducted by the United States Geological Survey near Fallon, Nev. At neither place have present results produced conclusive evidence, and the correct interpretation of the logs at hand, as bearing on the former lake histories of the basins, is subject to considerable uncertainty.

FOURMILE FLAT.

Alkali Valley, now called Fourmile and Eightmile flats and sometimes referred to as Sand Springs Valley, lies from 15 to 30 miles southeast of Fallon, in Churchill County, Nev., along the stage road from Fallon to Fairview and Wonder. Fourmile Flat consists of a salt-incrusted expanse covering 12½ square miles, the greater part of which is generally dry, but which is occasionally partly flooded to a depth of several inches.

A concentration of exceptionally pure salt covers more than a square mile in the southern portion of the area. During the sixties considerable salt was shipped on camels from Fourmile Flat to Virginia City for use in chlorinating the silver ores, and a smaller amount was obtained for domestic use. At present the production of salt from this deposit is exceedingly small, as rates for freighting by team are too high to make exploitation profitable.

Alkali Valley is an arm of the large basin formerly occupied by the Quaternary Lake Lahontan. The bottom of the valley has an elevation of 3,960 feet, and the Lahontan waters rose nearly to the 4,400-foot mark, as shown by terraces on the marginal slopes.

According to Russell[1] recent faulting has here developed a local drainage system, and the salt has been leached from the lacustrine sediments and concentrated in the lowest depression. Springs occur in the flat, and may have contributed in large measure to this saline

[1] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada; Mon. U. S. Geol. Survey, vol. 11, 1885, pp. 235.

accumulation by leaching beds lower in the series, but as yet this hypothesis is unsupported by any proof.

Subsequent to the writer's visit a test well, sunk to a depth of 36 feet by C. E. Watson under the direction of Hoyt S. Gale, showed a surface stratum of 7 feet of hard crystalline salt underlain by a soft black mud. At a depth of 26 feet a flow of water was encountered. Samples were analyzed as follows by R. K. Bailey in the Geological Survey laboratory:

Potash analyses of waters of Fourmile Flat.

Source of sample.	Collector.	Dissolved salts (dried at 105° C.) expressed as per cent of original sample.	K_2O content expressed as per cent of dissolved salts.
Water from "Big Ben" hole, one-half mile west of Kinney's house.	R. K. Bailey	28.90	2.37
Water from hole 200 yards south of "Big Ben"	do	29.10	.73
Water from hole 450 yards south of "Big Ben"	do	29.02	.73
Water 6 inches below surface of salt crust	do	29.53	.70
Water from flow encountered at 26-foot depth	do	26.51	.43
Concentrated brine from hole in salt crust one-half mile northwest of old salt works. Brine filled hole to level with surface salt crust.	J. H. Hance	31.44	1.21
Old well at Salt Wells station, 16 miles southeast of Fallon, Nev., and 8 miles north of Fourmile Flat. Well is 41 feet deep.	do	.35	(a)
Well about 3½ miles northwest of Salt Wells and 11½ miles north of Fourmile Flat. Well is 9 feet deep.	do	.47	(a)
Three dug wells at the old camp site of Sand Springs station on east edge of Fourmile Flat; now abandoned. Wells range from 1½ to 15 feet deep.	do	.15 .08 .27	(a)
Shallow well at old borax plant on Eightmile Flat, about 2 miles southwest of Salt Wells station.	do	.32	(a)
Dug well on Eightmile Point, just north of Fourmile Flat. Well is 30 feet deep.	do	1.34	

[a] Not determined.

The richest brine sample shows a potash content of only 2.37 per cent and consequently none of the waters are believed to offer any promise as a commercial source of supply of this material.

DIXIE SALT MARSH.

Dixie Salt Marsh, termed Osobb Valley in older reports, is described in the Fortieth Parallel Survey report.[1] It is east of and about 500 feet lower than the Carson Desert, Nev., from which it is separated by the Stillwater Mountains. Physiographic evidence, including a terraced gravel bar northeast of the marsh, indicates previous occupancy of this valley by a shallow lake, which apparently was too short lived to entrench its shore line deeply. Dixie Salt Marsh, which represents the lowest portion of the present valley, covers about 40 square miles. Near the center of the marsh an area of about 9 square miles is covered with a salt crust ranging from 1 to 5 feet in thickness. This crust is

[1] Hague, A., and Emmons, S. F., Final Rept. U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 707-708.

underlain by a saline mud, below which lies an alternating series of salt and mud.[1] When visited in July the surface salt was dry, but at other seasons of the year portions of the flat are flooded to a depth of 2 to 3 inches.

From 1861 to 1868 considerable salt was taken from this marsh and hauled by bull team to Virginia City for use in the treatment of the silver ores. Borax was obtained just north of the marsh and brought to Lovelocks for shipment by rail. Operations were discontinued some years ago, however, and at present no attempt is being made to develop the salt.

The following analysis is by R. W. Woodward:[2]

Analysis of salts from Dixie Salt Marsh.

Chloride of sodium	96.49
Sulphate of soda	1.91
Carbonate of soda	.96
Water	.52
Insoluble residue (mainly iron and lime)	.12
	100.00

As shown in this analysis, the sample was nearly pure sodium chloride, and the deposit may be valuable in the future.

Samples collected by the writer and analyzed by R. K. Bailey in the Geological Survey laboratory were reported as follows:

Analyses of salts from Dixie Salt Marsh.

Source of sample.	Dissolved salts (dried at 105° C.) expressed as per cent of original sample.	K_2O content expressed as per cent of dissolved salts.
Concentrated brine from 2½ miles southeast of old Dixie station, near center of marsh. Brine filled hole to level with salt crust	29.13	0.22
Water from dug well at old Borax works just north of marsh. Well was 9 feet deep with 4 feet of water	.92	(a)
Hot springs on southwest margin of marsh. Temperature, about 71° C	.07	(a)
Hot springs at mound about 12 miles northeast of marsh. Temperature, about 67° C	.11	(a)

a Not determined.

Thirty-one samples[3] from drilled wells ranging in depth up to 98 feet taken and analyzed by the Railroad Valley Co. show a potash content of 0.19 to 0.75 per cent of the total solids in saturated solutions. Therefore, so far as shown by available tests, the potash content of the marsh is commercially negligible.

[1] Hague, A., and Emmons, S. F., loc. cit. Also written communication from E. E. Free concerning work done by the Railroad Valley Co. in Dixie Valley.

[2] Hague, A., and Emmons, S. F., op. cit., p. 708.

[3] Written communication of E. E. Free.

NEBRASKA.

The sand-hill region in northwestern Nebraska embraces more than 16,000 square miles of upland lying between Niobrara River on the north and North Platte River on the south. A number of alkali lakes and ponds are scattered over the west-central portion of this region, especially in Cherry, Sheridan, Box Butte, Morrill, and Garden counties. Alliance is situated just west of the hills on the Chicago, Burlington & Quincy Railroad, which bisects the hill area.

The ponds range in size from less than an acre to 2 square miles, although the water content is directly dependent on the rainfall. The deeper ponds are fresh or comparatively so, but the shallow ones are too brackish even for stock. It is reported that during the summer months many of the ponds dry up, leaving a saline mud incrusted with alkali.

Occasional attempts have been made to utilize this alkali as a fertilizer, but the deleterious effects of the carbonate salts might be expected to prohibit such use, and results up to the present time have not apparently justified the projects. It was reported to the writer that some years ago a carload of the dry material was shipped to Omaha, where it was mixed with slaughterhouse refuse for fertilizing material, but the value of the product did not seem to encourage further development.

A sample of water from one of the more saline ponds submitted by parties interested in the development of the salts showed on analysis 19.32 per cent of dissolved salts. Of this dissolved material over 30 per cent was K_2O, indicating a potash content in the original brine of nearly 6 per cent.

Recent activity, stimulated by the general search for potash, has directed attention to the content of these ponds, and an attempt is now being made to extract the soda and potash in marketable form. Samples collected by C. L. Modessitt, of Alliance, and analyzed by J. W. Show at Omaha, showed an excess of potash over soda in many of the soluble residues. The attention of the Geological Survey was called to this feature, and the writer spent some time in traversing the area for the purpose of securing representative samples and determining the extent of the deposits. The samples are grouped under muds, brines, and saline residues or crusts. In addition to the samples included in the tables, 94 others were collected, but, as these contained less than 3 per cent of dissolved material (87 of them contained less than 2 per cent), further analysis of their potassium content was not completed.

Potash analyses of muds from western Nebraska.

No.	Source of sample.	Soluble portion expressed as per cent of sample.	K_2O content expressed as per cent of soluble portion.
26	1 foot below surface of Jesse Lake, 40 feet from shore	9.35	25.42
77	1 foot below surface of flat, one-fourth mile north of railroad, 2 miles east of Reno post office	3.04	14.80
112	Lake at Lakeside	3.58	12.03
115	4 feet below surface of Jesse Lake	4.63	28.92
116	7 feet below surface of Jesse Lake	4.07	24.78
126	Lake in sec. 1, T. 21 N., R. 46 W	3.47	13.20
	Average of 6 samples	4.69	19.86

Potash analyses of brines from western Nebraska.

No.	Source of sample.	Dissolved salts (dried at 105° C.) expressed as per cent of original sample.	K_2O content expressed as per cent of dissolved salts.
24	Shallow pit at edge of Jesse Lake	12.31	34.81
27	Pit 4 feet deep in Jesse Lake, 40 feet from shore	14.14	26.40
62	Pond 1 mile southwest of house on Star Ranch, sec. 17, T. 26 N., R. 43 W	3.21	35.85
73	Pond in sec. 19, T. 26 N., R. 44 W. (small)	8.15	15.50
74	Pond in sec. 19, T. 26 N., R. 44 W. (large)	4.70	31.40
79	Pond at F. C. Taylor's place, 3 miles east of Reno post office	7.20	23.14
85	Pond in northeast corner sec. 20, T. 26 N., R. 44 W	4.56	31.56
118	Middle of Jesse Lake	13.55	29.97
119	McCarty Lake, sec. 17, T. 23 N., R. 46 W	8.83	30.62
120	Pond one-half mile southeast of McCarty Lake	8.11	19.82
123	Richardson Lake, secs. 4 and 5, T. 22 N., R. 46 W	7.57	14.44
125	Lake in sec. 1, T. 21 N., R. 46 W	3.33	16.61
130	Thompson Lake, 15 miles southeast of Alliance	4.30	19.68
	Average of 13 samples	7.69	24.91

Potash analyses of saline residues from western Nebraska.

No.	Source of sample.	Soluble portion expressed as per cent of sample.	K_2O content expressed as per cent of soluble portion.
25	Crust on southeast margin of Jesse Lake	34.06	21.00
75	Alkali from road 8 miles west of north of Lakeside	4.62	6.16
78	Alkali sand south of railroad, 3½ miles east of Reno post office	8.51	11.27
94	Surface incrustation east end of Crevath Lake	34.05	17.17
113	Surface incrustation south edge of pond 1 mile west of north of Lakeside	30.85	2.40
117	Surface incrustation, Jesse Lake	20.25	17.39
132	East pond on Cluff place	8.97	29.70
134	Pond 1½ miles west of preceding	15.12	12.76
	Average of 8 samples	19.55	14.73

A complete analysis of these residues shows that they are markedly similar to the leachings of wood ashes and suggests one source of the alkali. These sand hills and adjoining meadows at one time supported a generous growth of brush and timber,[1] and the region has

[1] Bates, C. C., and Pierce, R. C., Forestation of the sand hills of Nebraska and Kansas: Bull. Forest Service No. 121, 1913, p. 17.

reached its present condition through repeated destructive fires. Prairie fires have also been of frequent occurrence and the natural leachings of these ashes may explain the concentrates in the depres, sions.

The alkali is disseminated in saline muds which underlie the ponds- and the latter are rather isolated from each other. Thus, in order to utilize the deposits the saline content must be leached from muds and recovered from solution at different places, and this would entail a number of evaporating units, which, because of the severe winters, could be used for a portion of the year only. Refining is necessary to render either the soda or potash of value and would add considerably to the cost.

NEW MEXICO.

ESTANCIA VALLEY.

The study of the water resources of the Estancia Valley [1] and the discovery there of lake terraces and of saline accumulations suggested the possible presence of potash in commercial quantity.

In recent geologic time the basin was evidently occupied by a lake, which on evaporation left its saline content disseminated in the valley sediments. Ground-water movement is now concentrating the more soluble material in small depressions in the lowest portion of the area.

A number of samples of the muds and incrustations collected by the writer were found on analysis to contain little potash.

Potash analyses of samples from the Estancia Valley, N. Mex.

Source of sample.	Mud. Soluble portion expressed as per cent of sample.	Surface crust. Soluble portion (dried at 105° C.) expressed as per cent of sample.	K_2O content expressed as per cent of soluble portion.
Pond just north of Laguna Chico (average of 3 samples)	11.93		0.71
		58.82	.42
Pond 2½ miles east of Estancia station (average of 3 samples)		90.56	.06
Laguna Chico (average of 4 samples)	12.17		.88
		74.14	.15
Pond north of Silio station (average of 4 samples)	10.32		1.23
		40.35	.38
Laguna del Perro (average of 3 samples)	10.08		.98
		73.90	.22
Laguna Salina (average of 3 samples)	13.78		.93
		74.60	.14
Laguna Salina (brine)	27.30		1.35
Average of 9 samples		68.49	.21
Average of 17 samples	11.59		.96

[1] Meinzer, O. E., Geology and water resources of Estancia Valley, New Mexico, with notes on groundwater conditions in adjacent parts of central New Mexico: Water-Supply Paper U. S. Geol. Survey No. 275, 1911.

Laguna Salina, a salt-incrusted pond about 600 acres in extent, contains a large deposit of nearly pure sodium chloride, which has long been used as a domestic supply by a number of ranchers. Under the present climatic conditions this pond is capable of supplying a large amount of high-grade salt, although no effort has been made to put out a refined product. Thin layers of bloedite crystals occur intercalated with the salt and mud strata.

CRATER SALT LAKE.

Crater Salt Lake, in western New Mexico, 50 miles south of Zuni and 80 miles west of Magdalena, has been briefly described by Darton.[1] Samples of the brine and the mud, collected by the writer from the bottom of the lake, were analyzed in the Geological Survey laboratory, the brine by R. K. Bailey, who reported 16.50 per cent dissolved salts, of which 0.29 per cent was potash, and the mud by W. B. Hicks, who found 13.12 per cent of soluble material, 0.61 per cent of which was potash. The dissolved material is nearly pure sodium chloride.

PLAYAS.

A lake at Playas, N. Mex., reported as alkaline, was visited by the writer, but was found to be comparatively fresh. At some seasons of the year the lake bed is entirely dry, but even then very little alkali is present. The basin has evidently contained a large lake in the past, but the valley sediments are notably free from alkaline salts.

CARLSBAD.

A small lake about 15 miles southeast of Carlsbad, N. Mex., reported as saline, was visited by the writer. The lake occupies a depression of about a square mile in extent, and is a concentration of local drainage. The water sample was analyzed by W. B. Hicks at the Geological Survey laboratory and found to contain 11.15 per cent of dissolved salts, 0.85 per cent of which was potash. The dissolved material is evidently leached from the adjacent rocks, which belong to the "Red Beds," and is concentrated in this shallow depression. An alkali flat extends south from the lake, but was covered with snow at the time of the writer's visit.

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[1] Darton, N. H., Zuni salt deposits, New Mexico: Bull. U. S. Geol. Survey No. 260, 1904, p. 565.

ARIZONA.

ADAMANA.

A well 305 feet deep, drilled in Permian beds at Adamana by the Santa Fe Railway, flows approximately 25 gallons a minute.[1]

Record of artesian well at Adamana, Ariz.

	Feet.
Sand and sandy clay	0– 55
Sandstone	55– 58
Cement gravel	58– 59
Sandstone (water slightly salty at 88)	59–108
Brown shale	108–151
Red shale	151–200
Hard brown and blue shale	200–205
Red shale	205–275
Sandstone	275–285
Hard brown shale	285–305

A sample of this water analyzed by W. B. Hicks at the Geological Survey laboratory was found to contain 4.89 per cent of dissolved salts, of which 0.35 per cent was potash.

The saline content of this well water, as also that of the lake near Carlsbad and Crater Salt Lake, in New Mexico, is derived from the "Red Beds" and is relatively smaller than that in ordinary American river and lake water, which, according to Clarke,[2] contains on the average 1.77 per cent of potassium (or 2.13 per cent potash) in the dissolved solids.

COCHISE FLAT.

Cochise Flat covers about 50 square miles and borders the Southern Pacific Railroad in southeastern Arizona. Gravel terraces near the town of Cochise indicate a former occupancy of this basin by a prehistoric lake. No deeply entrenched shore lines were seen, however, and the lake period or periods may have been of short duration. No notable concentration of salts seems to have taken place at the surface, and what little saline matter is present is mostly black alkali, with some sodium chloride. A sample of efflorescences gathered near a small pool was examined by W. B. Hicks, of the Geological Survey laboratory, and found to contain 11.74 per cent of soluble material, 1.29 per cent of which was potash.

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[1] Darton, N. H., Reconnaissance in northwestern New Mexico and northern Arizona: Bull. U. S. Geol. Survey No. 435, 1910, p. 79.

[2] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 491, 1911, p. 106.

NITER NEAR MELROSE, MONTANA.

By R. W. Richards.

Discovery.—At the close of his investigations of phosphates near Melrose, Mont., in 1912, the writer had the opportunity to spend a few hours in examining the niter deposit described in the following brief report. The trip was made with Mr. F. C. Moore, of Melrose, who claims to be the original discoverer. The deposit may not prove of economic importance; it is interesting, however, in that it affords another example of nitrate deposits in a region having a fairly abundant rainfall.

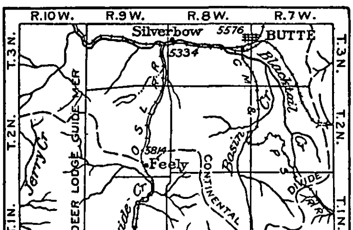


Figure 43.—Sketch map showing location of niter deposit near Melrose, Mont. Dashed line indicates approximate position of outcrop of Devonian limestone.

The deposit occurs along the face of cliffs of black limestone, presumably of Devonian age, on Camp Creek, about 3½ miles northeast of Melrose. (See fig. 43.) The nitrate occurs in little veinlets through the limestone, as a crust on the surface of the rock, in the talus accumulations beneath the ledges and also in small caves. The richest salts are found in the loose rock or talus at the base of ledges where protected from the weather by overhanging ledges. The niter salt consists of a snowy white to slightly yellowish mass of needle-like crystals.

The occurrence is essentially of the cave type described by Gale[1] in his discussion of nitrate deposits. Nests of rats or other animals were noted in the higher portion of the ledges.

Quality.—A series of samples were taken by the writer and analyzed by R. K. Bailey in the laboratory of the United States Geological Survey. Sample R 430 represents the purest material collected. It consists of a snowy white to slightly yellowish mass of acicular

[1] Gale, H. S., Nitrate deposits: Bull. U. S. Geol. Survey No. 523, 1912.

crystals, of which 86.09 per cent was found soluble in water. This soluble portion of the sample was shown to have the following composition:

Analysis of niter deposit near Molrose, Mont.

CaO	4.63
SO_3	8.19
Cl	8.61
N_2O_5	40.05
Na_2O	16.72
K_2O	22.05
	99.25

An attempt to express the composition in the form of salts probably present yields:

$CaSO_4$	13.94	
Na_2SO_4	3.30	
NaCl	20.42	
$NaNO_3$	21.77	61.25
KNO_3	39.48	
N_2O_5	1.19	

The excess of nitrogen pentoxide indicated in the second tabulation may be due to inaccuracy caused by applying Gooch and Gruener's iodometric determination to material containing larger quantities of nitrates than this method of analysis is adapted to show.

In the other samples the percentage of water-soluble material and amount of nitrogen pentoxide alone were determined. The latter is equivalent to a little more than half the amount of potassium present if combined in the form of that salt.

Analyses of supposed niter-bearing material.

	R 249.	R 430a.	R 430b.	R 431a.	R 431b.	R 431c.
Inorganic and insoluble	96.55	92.74	93.35	98.84	98.62	98.48
Water-soluble (percentage of original sample)	3.45	7.26	6.55	1.16	1.38	1.52
N_2O_5 (percentage of the water-soluble portion)	31.22	53.29	38.85	4.99	12.35	18.66

R 249 represents an average sample of a 5-foot face of black limestone.

R 430a represents an average sample of a 1-foot bed of sandy limestone with nitrates visibly included in thin streaks along joints and as crusts on surfaces.

R 430b represents a sample of the same bed, exclusive of all visible joints and surface coatings.

R 431a is a sample of a 10-inch bed of black limestone. The sample was washed in order to remove surficial salts. The remaining water-soluble portion was probably held in small cracks rather than disseminated through the rock.

R 431b is an average sample of the 4-foot face of black limestone, including at its top the 10 inches represented by R 431a.

R 431c is an average of a large sample of the talus at base of the limestone represented by sample R 431b.

Probable origin.—The occurrence of potash and soda-rich nitrates in limestone, where the calcium nitrate would naturally be expected, can not be readily explained from the data in hand. The nitrates contained in these salts may result from the decomposition of the rat or other guano, and the alkalies, potash and soda, may have been derived (1) from ordinary surface or ground water, (2) from solutions which have taken up these elements from igneous rocks, possibly the monzonite mass which is generally thought to underlie the region at depth, or (3) from minute proportions of these elements included in the limestone.

Value and extent.—The value of the deposits can not be safely estimated from the data which have been collected. Further exploration is needed to determine whether or not the potash and soda nitrates are included in the limestone back from the outcrop. General considerations suggest that the successful development of the deposits can be expected only under exceptionally favorable conditions. As the average soluble portion of the samples is only about 1 to 5 per cent, it appears that about 35 tons of rock would have to be treated to obtain 1 ton of the crude salts. This quantity if refined would yield theoretically about 440 pounds of soda niter and about 790 pounds of potash niter, the former being at present worth about $24 and the latter about $41, making a gross yield of about $1.80 per ton of rock treated. It is not, however, practical to estimate a theoretical total extraction, either of all the salts present in the rock or of the nitrate portion to be refined from the crude salts. Better returns might be obtained by treating the loose rock fragments which lie at the base of the cliffs, but such material is very meager in amount.

The location of the limestone belt east of Melrose, in which the niter occurs, is shown on the sketch map (fig. 43). Other areas of the same limestone are known in western Montana, but so far as known niter has not been reported from them.

The Devonian limestone that is known to be locally associated with nitrate deposits may be distinguished from the other limestones of the region that are not yet known to be so associated by its darker color. The other limestones are mainly light bluish gray and brown.

Suggestions for prospecting.—Interest in the better understanding of the actual nature of these deposits, as well as the hope of developing something of value, may lead to a more thorough prospecting of similar rocks in the surrounding area. In this work special attention may be given to the outcrops of limestones and particularly to such mine workings as have recently penetrated the limestones at a distance from the outcrop, so that samples may be obtained which represent the average content of the rock at depth and not the surface enrichment.

SURVEY PUBLICATIONS ON SALINES, INCLUDING SALT, BORAX, AND SODA.

The more important publications of the United States Geological Survey on the natural lime, sodium, and potassium salts included in this group are those listed below.

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.

ARNOLD, RALPH, and JOHNSON, H. R., Sodium sulphate in Soda Lake, Carriso Plain, San Luis Obispo County, Cal.: Bull. 380, 1909, pp. 369–371. 40c.

BREGER, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: Bull. 430, 1910, pp. 555–569.

CAMPBELL, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: Bull. 200, 1902, 23 pp. 5c.

——— Borax deposits of eastern California: Bull. 213, 1903, pp. 401–405. 25c.

CHATARD, T. M., Salt-making processes in the United States: Seventh Ann. Rept., 1888, pp. 491–535. $2.

DARTON, N. H., Zuni salt deposits, New Mexico: Bull. 260, 1905, pp. 565–566. Exhausted.

DOLE, R. B., Exploration of salines in Silver Peak Marsh, Nevada: Bull. 530, 1913, pp. 330–345.

ECKEL, E. C., Salt and gypsum deposits of southwestern Virginia: Bull. 213, 1903, pp. 406–416. 25c.

——— Salt industry of Utah and California: Bull. 225, 1904, pp. 488–495. 35c.

GALE, H. S., Nitrate deposits: Bull. 523, 1912, 36 pp.

——— Borax in 1912: Mineral Resources U. S. for 1912, 1913.

——— The search for potash salts in the desert basin region: Bull. 530, 1913, pp. 295–312.

HAYES, C. W., The Gila River alum deposits: Bull. 315, 1907, pp. 215–223. 50c.

KINDLE, E. M., Salt resources of the Watkins Glen district, New York: Bull. 260, 1905, pp. 567–572. Exhausted.

PACKARD, R. L., Natural sodium salts: Mineral Resources U. S. for 1893, 1894, pp. 728–738. 50c.

PHALEN, W. C., Salt and bromine in 1912: Mineral Resources U. S. for 1912, 1913.

——— Potash salts, their uses and occurrence in the United States: Mineral Resources U. S. for 1910, pt. 2, 1911, pp. 747–767.

——— Potash salts, summary for 1912: Mineral Resources U. S. for 1912, 1913.

——— The occurrence of potash salts in the bitterns of the eastern United States: Bull. 530, 1913, pp. 313–329.

Richardson, G. B., Salt, gypsum, and petroleum in trans-Pecos Texas: Bull. 260, 1905, pp. 573–585. Exhausted.

Schultz, A. R., Deposits of sodium salts in Wyoming: Bull. 430, 1910, pp. 570–588.

Schultz, A. R., and Cross, Whitman, Potash-bearing rocks of the Leucite Hills, Sweetwater County, Wyo.: Bull. 512, 1912, 39 pp.

Yale, C. G., and Gale, H. S., Borax in 1912: Mineral Resources U. S. for 1912, 1913.

SULPHUR AND PYRITE.

SULPHUR DEPOSITS IN PARK COUNTY, WYOMING.

By D. F. Hewett.

Location and surroundings.—The group of sulphur deposits here described has been known locally for a number of years, but as efforts have recently been made to determine their extent, a brief examination of them was made by the writer in connection with routine field work in the region during the summer of 1912. The deposits are 12 miles south of those in Sunlight Basin, which were examined by the writer in 1911.[1] They lie at an elevation of 6,700 feet along Sweetwater Creek, about 2 miles north of its junction with the North Fork of Shoshone River, near which is situated the summer settlement of Wapiti, about 32 miles west of Cody on the road to the Yellowstone Park.

From its source near Sylvan Pass to a point about 25 miles west of Cody the North Fork of Shoshone River flows eastward, for the most part in a deep, narrow valley which only for short stretches widens into grassy or timber-covered parks. Sweetwater Creek, one of the numerous tributaries which descend from the snow fields of the main ridges of the Absaroka Range, rises among a group of prominent peaks forming a ridge that separates the waters of Sunlight Creek on the north from those of Shoshone River on the south. The valley of Sweetwater Creek is narrow and the bordering slopes are steep and rugged. In common with most of the streams of similar relations in the region, the creek only locally flows on bedrock, the greater part of its erosional work being the removal of the large quantities of débris which are liberated by frost on the neighboring slopes and are delivered as alluvial fans from tributary gulches.

The sulphur deposits are confined to a narrow strip adjoining Sweetwater Creek on the east, and the area within which sulphur has been found does not exceed 20 acres.

Geology.—The superficial rocks in the vicinity of the sulphur deposits are wholly igneous and constitute the lower portion of a great thickness of lava flows and breccias from which the Absaroka Mountains have been carved. The geology of the region has been studied and described by Hague,[2] who states that these rocks have a maximum thickness of 11,000 feet and rest upon the eroded surface

[1] Hewett, D. F., Sulphur deposits of Sunlight Basin, Wyoming: Bull. U. S. Geol. Survey No. 530, 1913, pp. 350–362.

[2] Hague, Arnold, Absaroka folio (No. 52), Geol. Atlas U. S., U. S. Geol. Survey, 1899.

of folded sedimentary rocks which range in age from Cambrian to Tertiary. In Sunlight Basin, 14 miles north, the igneous rocks lie upon Madison (Carboniferous) limestone, and on the North Fork of Shoshone River, 2 miles south, they lie upon Tertiary sandstones and shales, probably of Wasatch age. The total thickness of these sedimentary rocks on Shoshone River near Cody is 18,000 feet.

The igneous rocks along Sweetwater Creek are consolidated breccias of augite andesite porphyry. They show local variations in composition, but the most common rock type is reddish brown and contains easily visible crystals of plagioclase and augite. It is essentially similar to the red variety of andesite which was observed near the deposits in Sunlight Basin.

The sulphur deposits.[1]—The sulphur deposits are confined to a narrow belt about 1,400 feet long adjoining the east bank of Sweetwater Creek. The largest deposits occur in the strip of débris formed by the merging of alluvial fans from two dry gulches with talus material which has been washed from near-by slopes. Several smaller deposits lie along the slope of the ridge to the east of the stream.

The largest deposit, which is the southernmost, is exposed in the bank of the stream where it cuts the widest portion of an alluvial fan. No sulphur was visible on the surface here before pits were sunk, but it has since been shown to exist sporadically over an area of about 2 acres. The débris consists of angular fragments of rock which range in size from fine sand to pieces 2 inches in diameter, and, though derived from dark igneous rocks, it is practically white over an area of about 6 acres. The sulphur occurs as bands of crystalline aggregates which fill the interstices between the fragments. A pit sunk on the middle of the fan shows the following section:

	Feet.
Soil and débris free from sulphur	2
Fine débris containing traces of sulphur	1
Débris containing 5 to 10 per cent of sulphur	2
Débris containing traces of sulphur	2
Débris containing 30 to 50 per cent of sulphur	1
Bedrock not penetrated.	

Three other trenches have been dug within this deposit, of which the northernmost shows the following section:

	Feet.
Soil and brown to white débris; no sulphur	2
White débris containing 5 to 10 per cent of sulphur	2
White débris containing 15 to 30 per cent of sulphur	3
White débris containing 5 to 10 per cent of sulphur	1
Dark-green débris free from sulphur but containing a velvety efflorescence of alkali alum, crusts of melanterite (and possibly a ferric sulphate), and thin films of a yellow metallic mineral, probably marcasite	3
Bedrock not exposed.	

[1] The term "deposit" will be applied in this description to those isolated portions of the area within which the rocks are bleached and decomposed and contain appreciable amounts of sulphur, as compared with the remainder of the area in which the rocks are essentially fresh and wholly free from sulphur. The term has no economic significance.

The features shown in this trench are closely similar to those observed in deposits near the level of ground water in Sunlight Basin and, aside from their bearing on the association of the sulphur, are interesting as showing the probable origin of the marcasite. The ferrous and ferric sulphates are formed by the combination of the iron oxides of the igneous rock with sulphuric acid produced by the complete oxidation of the hydrogen sulphide in the gases. It is well known from laboratory experience that at ordinary temperatures and pressures hydrogen sulphide does not precipitate a sulphide of iron from an acid solution of ferrous sulphate, but as the marcasite is undoubtedly deposited by reaction of these substances, it must be that the solutions of ferrous sulphate are neutral, owing to their seepage downward through the igneous rocks. The transition from a zone of white rock fragments to one of green fragments indicates that the white rock has been leached of iron salts, which are slightly concentrated in the ferrous state near the level of ground water.

A comparison of the sections of the trenches shows that the sulphur-bearing material occurs as one or more lenticular beds essentially parallel to the present surface of the débris but practically covered with débris free from sulphur. The odor of hydrogen sulphide is strong in the trenches, but no accumulation of heavy gases, such as carbonic acid, was noticeable.

In a deposit about 1,200 feet north of that just described sulphur occurs in two distinct associations. It cements the débris of a small alluvial fan near the stream and forms a crust coating the walls of small crevices in bedrock, a spur of which projects from a ridge to the east and adjoins the fan on the north. There are two open crevices within 80 feet along the creek, and the rock, though bleached over the greater portion of the surface, contains sulphur near the crevices only. The greater portion of the sulphur occurs as a cement of angular fragments of rock, which are liberated by weathering from the adjacent slopes. Gases containing hydrogen sulphide and carbonic acid issue freely from the crevices. Sulphur is also found on the surface of the alluvial fan over an area about 100 feet square. There has been no prospecting at this locality.

In addition to these deposits the rock on the surface of the ridge east of Sweetwater Creek up to an elevation of 6,800 feet is locally bleached and decomposed, and in the vicinity of the areas of most intense bleaching sulphur occurs as thin crusts partly enveloping fragments of the breccias or as numerous minute crystals studding the surfaces. Four such deposits were noted, none of which covered an area greater than 50 feet square.

Siliceous sinter and travertine, such as in many places accompany sulphur deposited by hot springs, are conspicuously absent.

Oil spring.—An interesting feature of the sulphur deposits is the proximity of a petroleum spring, which lies on the west bank of Sweetwater Creek, within 100 yards of the largest sulphur deposit. It is reported that during the summer of 1911 sufficient oil was collected to supply the lamps at a temporary camp. At the time of the writer's visit in 1912 the original site of the spring was covered with water, but in a hole that was dug to a depth of 3 feet within 2 feet of the water's edge enough oil was collected to demonstrate its presence. The oil that was previously collected is reported to have been light and clear. The sand at this point is dark brown and has an asphaltic odor, but otherwise is such as would form bars along a swiftly flowing mountain stream.

Genesis.—These sulphur deposits, though much smaller, are essentially similar to those which occur in the upper portion of Sunlight Basin. They appear to have been formed by the decomposition of hydrogen sulphide contained in gases that issue from crevices in the igneous rocks. There is good reason for believing that the gases are similar in composition to those which were collected in Sunlight Basin and which on analysis were shown to contain carbonic acid, nitrogen, and methane, as well as hydrogen sulphide.

The sulphur-bearing débris, being highly porous, offers far better conditions for the aeration and oxidation of hydrogen sulphide than the massive rocks, which are thought to contain very little, if any, sulphur beyond that in the open crevices.

The thickness of débris above water level is probably in places as much as 25 feet, and a good portion of this may locally be sulphur-bearing, but it is extremely doubtful whether any sulphur will be found below the water, which effectually prevents oxidation of the gases and deposition of sulphur.

Though it would at first seem necessary that any explanation of the origin of the sulphur should explain that of the petroleum also, this is not necessarily the case. It seems highly probable that the sulphurous gases have ultimately a deep-seated or igneous origin, the gases rising to the surface along fractures. These fractures would necessarily intersect the sedimentary rocks which underlie the lavas and breccias and which are known to contain oil and gas locally along Shoshone River, 30 miles east.

Economic importance.—The sulphur deposits are small, and under the conditions existing at present in the American sulphur industry there is little chance that they can be exploited with profit. The fact that sulphur has been found in the débris where none was exposed on the surface makes it at least possible that the alluvium contains considerably more than is at present known. Even should this prove to be true, it is still doubtful whether the deposits can be utilized unless the local demand becomes great.

SURVEY PUBLICATIONS ON SULPHUR AND PYRITE.

The list below includes the important publications of the United States Geological Survey on sulphur and pyrite. 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.

Adams, G. I., The Rabbit Hole sulphur mines, near Humboldt House, Nev.: Bull. 225, 1904, pp. 497–500. 35c.

Davis, H. J., Pyrites: Mineral Resources U. S. for 1885, 1886, pp. 501–517. 40c.

Eckel, E. C., Gold and pyrite deposits of the Dahlonega district, Georgia: Bull. 213, 1903, pp. 57–63. 25c.

——— Pyrite deposits of the eastern Adirondacks, New York: Bull. 260, 1905, pp. 587–588. Exhausted.

Hess, F. L., A sulphur deposit in the San Rafael Canyon, Utah: Bull. 530, 1913, pp. 347–349.

Hewett, D. F., Sulphur deposits of Sunlight Basin, Wyoming: Bull. 530, 1913, pp. 350–362.

Larsen, E. S., and Hunter, J. F., Two sulphur deposits in Mineral County, Colorado: Bull. 530, 1913, pp. 363–369.

Lee, W. T., The Cove Creek sulphur beds, Utah: Bull. 315, 1907, pp. 485–489. 50c.

Phalen, W. C., Sulphur, pyrite, and sulphuric acid in 1912: Mineral Resources U. S. for 1912, 1913.

Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: Prof. Paper 66, 1909, 258 pp. $1.50. [Sulphur, pp. 109–110; pyrite, pp. 113–114.]

Richards, R. W., and Bridges, J. H., Sulphur deposits near Soda Springs, Idaho: Bull. 470, 1911, pp. 499–504.

Richardson, G. B., Native sulphur in El Paso County, Tex.: Bull. 260, 1905, pp. 589–592. Exhausted.

Spurr, J. E., Alum deposits near Silver Peak, Esmeralda County, Nev.: Bull. 225, 1904, pp. 501–502. 35c.

Woodruff, E. G., Sulphur deposits at Cody, Wyo.: Bull. 340, 1908, pp. 451–456. 30c.

——— Sulphur deposits near Thermopolis, Wyo.: Bull. 380, 1909, pp. 373–380. 40c.

MISCELLANEOUS.

LATE DEVELOPMENTS OF MAGNESITE DEPOSITS IN CALIFORNIA AND NEVADA.

By Hoyt S. Gale.

INTRODUCTION.

By far the greater part of the magnesite occurring in the United States is found in California, where numerous deposits are widely distributed throughout the Coast Ranges and on the western slopes of the Sierra Nevada. Recently reports of deposits at two localities in Nevada have been received. It is said that some deposits of this material are also known in Arizona and western Texas, and small veins, described as chiefly of mineralogic interest, have been found in North Carolina, Pennsylvania, Maryland, and Massachusetts. A number of these deposits, especially in California, are of considerable size and yield magnesite of excellent quality, which is probably excelled by few if any of the foreign deposits and is superior in purity to much of that mined abroad.

Bulletin 355 of the United States Geological Survey, entitled "Magnesite deposits of California," by Frank L. Hess, was based on field examinations of the California deposits made in 1905 and during the winter of 1906–7. Since that time new deposits have been opened, consumption has increased, and inquiries are constantly being received at the Survey for information relating to the occurrence and utilization of this material. The present paper has therefore been prepared to supplement the earlier publication.

PRODUCTION AND CONSUMPTION OF MAGNESITE.

The accompanying diagram (fig. 44) represents the production of magnesite in this country in terms of the raw rock as mined. The figures for production are those given in the annual volume of Mineral Resources of the United States compiled and published by the Geological Survey.

Conditions governing the production and consumption of domestic magnesite have not changed in any marked degree in recent years. The presence of many good deposits of this material in California must continue to furnish the impetus which will tend to put our own product on the market as soon as natural conditions will allow. At present by far the largest part of the magnesite used in the United

States is imported and is consumed in the Eastern States, largely for making refractory products. In 1912 the quantity of crude and calcined magnesite imported, exclusive of the refined magnesia salts imported for medicinal or other purposes, was, when reduced to terms equivalent to the calcined rock, approximately 20 times the domestic production. It is reported, doubtless correctly, that the magnesite mined in Greece, Austria, Norway, and elsewhere, where labor is cheaper than in this country and where port facilities are possibly better, has a considerable commercial advantage over our own product. An ocean rate of perhaps only $1.50 or $2 a ton, coupled with the other advantages of foreign magnesite, overbalances even inferiority in grade of some of the imported product.

Like some other nonmetallic mineral products, magnesite occurs in California and other States in numerous deposits that undoubtedly

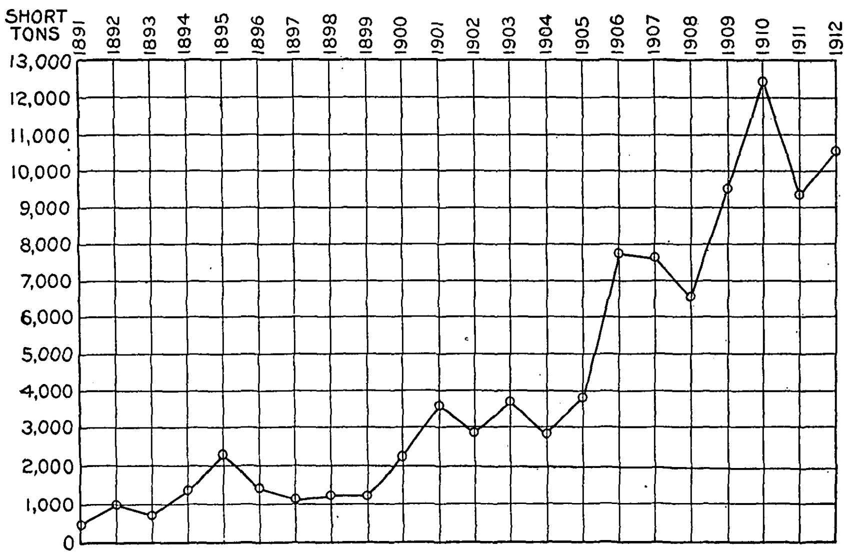


FIGURE 44.—Production of crude magnesite in the United States, 1891-1912.

have considerable potential value, but until conditions in this country will justify a steady, continuous production on a scale to permit efficient mining operations, the foreign product will probably continue to be largely used. Nearly all the California magnesite is consumed on the west coast, the greater part being used in paper manufacture. Overland freight rates to the Eastern States amounting to $10 a ton or more for the present effectually preclude the western magnesite from competing with the imported product in these States.

Considerable interest in the home production of magnesite has been aroused of late in anticipation of the possible advantages that may accrue with the opening of the Panama Canal, in the hope that this new route may enable California producers to reach the eastern ports at sufficiently low freight rates to allow them to place their product on the eastern market.

During 1912, however, foreign magnesite was received at California ports to the amount of about 400 tons of raw rock and nearly 600 tons of calcined, where the calcined (dead burned) rock has been quoted at $23 to $25 or more a ton. Sporadic demands for a few hundred tons of the domestic magnesite are said to have been at times difficult to fill. This condition is not the result of lack of material, but is due to the present limitation and uncertainty of the market, which permits few home properties to operate continuously or on a scale to promote the economy of production which would place the home product in a position to meet competition.

The following statistics concerning imports of magnesite have been obtained from the Bureau of Foreign and Domestic Commerce, Department of Commerce. They include two statements relative to the imports of magnesite "calcined not purified"—one showing the countries of shipment or nominal origin and the other the ports and customs districts into which the material was imported. Data as to the countries from which the crude magnesite was imported are not available.

Imports of magnesite showing ports of receipt during the year ending June 30, 1912.

Customs district.	Crude.	Calcined.
	Short tons.	*Short tons.*
New York, N. Y.	13,864	111
Boston and Charlestown, Mass.	65	3,028
Newark, N. J.	25	.....
Champlain, N. Y.	276	27
Buffalo Creek, N. Y.	56	56
Chicago, Ill.	.....	27
Memphremagog, Vt.	.....	90
Vermont	3	61
Philadelphia, Pa.	.....	76,171
New Orleans, La.	.....	22,805
Puget Sound, Wash.	1	23
Los Angeles, Cal.	.....	248
San Diego, Cal.	96	96
San Francisco, Cal.	321	195
	14,707	102,938

Imports of magnesite calcined, not purified, in short tons, for the years ending June 30, 1910–1912, showing countries of shipment or nominal origin.

	1910	1911	1912
Europe:			
Austria-Hungary	101,751	143,392	99,104
Belgium	.....	33	25
Germany	2,719	1,426	689
Greece	927	.....	114
Italy	.....	28	.....
Netherlands	1,712	2,974	2,410
Norway	28	121	163
United Kingdom (England)	409	2	61
North America:			
Canada	13	296	234
Mexico	.....	.....	81
Asia: East Indies, British	.....	.....	57
	107,560	148,272	102,938

GENERAL CHARACTER AND DISTRIBUTION OF MAGNESITE DEPOSITS.

The mineral magnesite is essentially the normal carbonate of magnesium, expressed chemically by the formula $MgCO_3$. It usually occurs as a dense white massive mineral, rarely showing any crystalline structure, and in its most common massive form it is entirely devoid of cleavage or regular partings. It has conchoidal fracture, showing a smooth white opaque surface resembling broken porcelain. Less pure varieties may be stained and colored or have a coarser granular structure.

According to Dana magnesite has a specific gravity of 3 to 3.12. Therefore a cubic foot of the solid mineral weighs about 190 pounds. It is rated as 3½ to 4½ in the scale of hardness. The theoretically pure mineral contains 52.4 per cent of carbon dioxide (CO_2) and 47.6 per cent of magnesia (MgO). As the mineral occurs in nature it includes various proportions of silica, clay, or serpentine and to a greater or less extent the oxides of iron.

Most of the deposits of magnesite known are associated with intrusive igneous rocks such as peridotite and allied basic rocks, which are composed essentially of minerals rich in magnesia, like olivine and the pyroxenes. As the magnesite occurs in veins and lodes, in part replacing the igneous rock, it seems quite clear that it is derived mainly from the alteration of the intrusive magnesian rock. In the original rock the magnesia is present principally in the form of silicates. By alteration of the silicates to the carbonate, magnesite, the silica is set free. The magnesite veins commonly occur in zones of more intensive alteration in the magnesian silicate country rocks, and these zones are most conspicuously characterized by secondary silica, as opal, chalcedony, or quartz. One of the most common products of the decomposition by hydration or weathering of magnesia-rich silicate rocks is the green mineral serpentine, a magnesian silicate, with water in combination, and this alteration takes place so extensively over the surface areas of the exposures of the basic intrusive rocks here described that the whole mass is commonly referred to as "serpentine," although that term strictly signifies a specific mineral rather than a rock that is more or less diverse in composition.

"Serpentine" rock is widely distributed throughout the Coast Range and also in the Sierra Nevada of California. Reports of magnesite occurrences elsewhere indicate that similar rocks also exist in Nevada and outside of the areas concerning which definite geologic data are now available.

USES OF MAGNESITE.

The principal uses of magnesite are summarized below. The data on this subject have been of necessity compiled from published returns and from hearsay, but care has been exercised to make this statement as accurate as possible.

1. In refractory products, such as brick, furnace hearths, and crucibles.
2. As magnesium sulphite for the digestion and whitening of wood-pulp for paper.
3. In crude form for the manufacture of carbon dioxide.
4. Calcined and ground for oxychloride or Sorel cement.
5. In crude or calcined form for miscellaneous applications.
6. As refined magnesia salts for medicinal and other uses.

Refractory products.—The uses of magnesite for refractory products constitute perhaps its most important application in the industries. Made into refractory bricks it is used as linings for basic steel furnaces. In "dead burnt" calcined form as originally burned or as brick, the magnesia is used as a refractory lining for open-hearth furnaces and converters in the steel industry, for rotary kiln linings in Portland cement manufacture, for furnace hearths, crucibles, cupels, etc.

It is commonly believed that the most refractory magnesite is the "dead burnt" product derived from magnesite containing little or no lime, silica, oxide of iron, or alumina. The presence of lime in magnesite bricks used at high temperatures is said to cause them to disintegrate more readily, and in basic steel furnaces the lime is believed to cause the phosphorus to pass into the hearth instead of the slag, the hearth thereby becoming rotten. Silica, oxide of iron, and alumina are supposed to be objectionable because they have a tendency to lower the fusing point. On the other hand, analyses of the imported magnesite, which constitutes by far the greater part of the product consumed in this country and is assumed to represent a standard of desirable composition for practical purposes in the metallurgical industry, generally show 3 to 4 per cent of silica, 6 to 8 per cent of iron, and 4 per cent of lime. The percentage of alumina usually found is said to be so small that it need not be considered.

Apparently there is some divergence of opinion as to the most desirable composition of magnesites to be adopted for metallurgical refractory uses.

Paper manufacturing.—The availability of magnesite in the deposits in California has led to the considerable use of magnesium bisulphite in the manufacture of wood-pulp paper in that State.

In the sulphite process of paper making [1] the wood (mostly coniferous wood) is boiled with a disintegrating agent so that it breaks

[1] Thorp, F. H., Outlines of industrial chemistry, 1909, pp. 522-523.

down into a mass of pulp, which is afterward rolled into paper. The disintegrating agent is sulphurous acid or common bisulphite of calcium or magnesium. Magnesium bisulphite is more stable than calcium bisulphite, it dissolves the noncellulose matter more completely, and it has an additional advantage in that the residues left in the stock when it is used are not afterward injurious to sizing agents. Sodium bisulphite gives a better product than either the magnesium or the calcium salt, and strong liquors can be made from it, but it is too expensive for general use.

It is estimated that the greater part of the California magnesite is now used in the manufacture of paper by this process. The deposits near Porterville, which have been for years the largest producers, have been worked primarily for this purpose.

Manufacture of carbon dioxide.—The manufacture of carbon dioxide from raw magnesite consists in the decomposition of the magnesium carbonate by ordinary calcination, the carbon dioxide being recovered, purified, and compressed, and the residual magnesia being also available as a by-product. The operation of this process is described by Hess,[1] who gives a diagram showing details of one of the plants. It is understood that the use of magnesite for this purpose has now been largely or wholly abandoned on the Pacific coast, as carbon dioxide can be produced more cheaply as a by-product in other processes; for instance, it is now made as one of the products of fermentation in a distillery.

Cement.—The use of magnesite for the manufacture of oxychloride or Sorel cement is apparently a promising field. This product consists of a mixture of finely ground calcined magnesite with magnesium chloride and when it has been wet sets in an exceedingly strong, somewhat elastic cement. The material for this cement is marketed under many trade names, being especially referred to as a sanitary flooring. For flooring, wainscoting, and similar uses the cement is mixed with wood flour, sawdust, cork dust, or some similar material. When well and successfully laid, magnesite cement has some important advantages over other cements for this purpose. It produces a smooth, even floor, which may be laid in thin sheets over large surfaces without cracking. It takes colors readily, and is susceptible of a good polish with oiling or waxing. It is laid in a plastic state on wood or concrete. Its surface seems to have a resilience not apparent in ordinary cement, and it does not pulverize or grind to dust. This cement is said to have been very extensively used abroad for flooring and to be gradually coming into wider use in this country. It is also reported to have found a use in the manufacture of artificial marble and fine tiles.

There are, however, practical difficulties to be encountered in the manipulation of magnesia cements, which are not yet wholly under-

[1] Bull. U. S. Geol. Survey No. 355, 1908, pp. 8, 9.

stood and have at times led to some dissatisfaction with the material and to criticism, possibly not always merited. It would seem to be desirable that a competent investigation of the technology of this subject should be undertaken in the interest of a potentially very useful product.

Other uses.—Magnesite in both crude and calcined form finds numerous miscellaneous applications, among which may be mentioned its use as heat-insulating pipe covering. For this purpose it is commonly mixed with asbestos fiber, and the artificial magnesia alba levis seems to be best. Magnetite is said to be used as an absorbent in the manufacture of dynamite, as an adulterant in paint, and as a preventive of scale in boilers in which sulphurous waters are used. It has been tried with some success as a binder for briquetting coal, where it has the disadvantage common to all inorganic binding materials, namely, that they increase the ash without adding to the combustible portion of the fuel.

The use of magnesite in a fireproof or fire-retarding paint is also reported to be increasing. Wood and burlap coated with a paint made of magnesite are said to resist fire so that while they can be burned by the direct application of heat and flame, the fire will not spread beyond the area actually exposed to the flame.

Refined magnesia salts are used for medicinal and toilet purposes. The commercial preparation known as magnesia alba is a basic carbonate of slightly varying composition, according to the conditions of production. It is usually prepared by precipitation of either the commercial sulphate or chloride of magnesium with sodium carbonate. Epsom salts (magnesium sulphate) is derived from the deposits at Stassfurt, Germany, and is imported on a considerable scale but is also manufactured by the chemical treatment of magnesite. A considerable quantity of magnesia quoted as "medical, calcined" is imported annually, probably representing a purified product for medicinal or other uses.

DEPOSITS IN CALIFORNIA AND NEVADA.

SUMMARY.

A number of recent developments in reference to new deposits or deposits in which interest has been revived have led to a partial review of the magnesite industry of the West by the writer. Some field examinations were made in 1912, and the resulting descriptions and records are given in the following pages. In general it is designed that these accounts shall supplement rather than duplicate the matter contained in Hess's report, already cited.

The deposits visited are here described by counties, beginning with the more northerly and proceeding toward the south. A few of these descriptions have already been published with the statistical summary in the annual volume of Mineral Resources of the United States.

CALIFORNIA DEPOSITS.

SONOMA COUNTY.

EAST FORK OF AUSTIN CREEK OR RED SLIDE.

The occurrences of magnesite in the Coast Range belt, Sonoma County, Cal., have been described by Hess,[1] and the following notes are added mainly because of late activity looking to the further development of the deposits on East Fork of Austin Creek. These deposits were examined by the writer, by courtesy of Mr. A. B. Davis, September 16, 1912. At that time the most convenient means of access was to go on horseback by road and trail about 8½ miles north from Cazadero, the route crossing the steep divide between the branches of West and East forks of Austin Creek and descending at the Heider ranch, on East Fork. There is a wagon road from Guerneville to the deposits, but it is steep and difficult as well as long. A new road has been surveyed for the development of the magnesite properties, following down East Fork of Austin Creek to its junction with West Fork, a distance of about 10 miles, there meeting the railroad at Watson's, 2 or 3 miles above the junction of the forks of Austin Creek and Russian River. According to statements made by Mr. Davis this route offers no unusual difficulties for transportation, is of uniform and light grade, and when a road is built will afford a ready

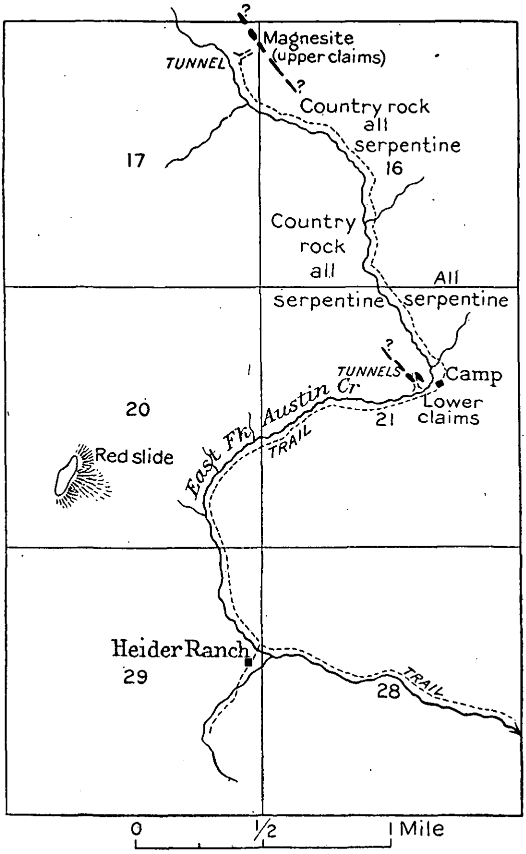


FIGURE 45.—Map showing magnesite deposits on East Fork of Austin Creek, Sonoma County, Cal.

[1] Op. cit., pp. 26–28.

means of getting the ore down to the railroad shipping point, at a relatively favorable distance from San Francisco or the Pacific coast.

The deposits are located in T. 9 N., R. 11 W., and consist of two groups of claims, which are referred to as the upper and lower claims. The lower claims lie on the north and west side of East Fork of Austin Creek in a bend of the main stream, a little over a mile northeast of the Heider ranch. Just above the prospects of the lower claims the main creek flows from the north or northwest. The tunnel on the upper claims is situated on the east bank of the creek 1½ miles N. 30° W. from the lower tunnels. A wagon trail runs between the two properties and continues downstream past the Heider ranch.

The alignment and level line of a new road survey extends as far upstream as the tunnels on the lower claims. Several large outcrops of magnesite show on the northwest bank of the creek, not far above water level, and large blocks or masses of magnesite are to be found in natural slide rock at the base of the slope and also in the creek bed.

As stated by Hess [1] large areas of serpentine, whose limits have not been defined, occur in this portion of the country, and it is in this serpentine that the magnesite veins occur. The Red Slide, a prominent landmark near the crest of the high ridge southwest of the magnesite claims, is probably a part of the same serpentine area, and the rock exposures in the canyon between the upper and lower claims consist almost entirely of serpentine.

So far as has been determined the magnesite veins of both groups of claims lie in a fairly well defined belt that trends N. 30° W. from the lower claims. This trend is approximately parallel to the upper course of East Austin Creek, crossing it, however, so that the croppings of the southern or lower group of claims are west of the creek and those of the upper claims lie east of it. It is not supposed that the veins are continuous throughout this belt, but it appears likely that there may be a more or less well defined zone of brecciation along which deposits or traces of deposits may be found at intervals. The serpentine in the road-cut between the two groups of claims was noted to be a mass of much-shattered rock containing magnesite stringer veins as much as an inch or so in thickness. No attempt was made during the writer's brief visit to trace this zone, even within the limits of the located claims.

The developments on the lower claims were apparently in much the same condition as when they were examined by Hess.[2] The accompanying diagram (fig. 46) represents roughly the sections exposed by the two main tunnels of this lower group of claims, and also the site from which the portion represented in the sample analyzed was taken. The lower of the two tunnels (*a*, fig. 46) was somewhat more than 200

[1] Op. cit., p. 26. [2] Idem, pp. 26, 27; Pl. V, *B*.

feet in, starting on the outcrop of a vein 6 to 9 feet in width. This tunnel is driven on the vein N. 10° W. for about 50 feet, then turns diagonally off into country rock, extending about 180 feet in a northeasterly course. One other small vein of magnesite, step-faulted, trending N. 20° W., was encountered near the end of this drift. The upper tunnel (*b*, fig. 46), which is supposed to cut about the same rocks as the lower tunnel at an elevation 50 feet higher, is only a little over 100 feet in length, but shows a much larger cross section of magnesite veins. None of the veins have been followed by drifting for any considerable distance, and their continuity or extent is very uncertain. Like the lower tunnel this working is driven in at the outcrop of a large ledge exposing about 12 feet of magnesite, but apparently the entry does not follow the trend of the ore body. The west wall of the vein is distinct, stands nearly vertical, and trends N. 40° W., while the tunnel starts in at about N. 5° W. Magnesite can be seen in the serpentine at the west of the entrance, and for the first 50 feet the tunnel runs diagonally into a more easterly vein, which shows a good 5-foot face at the end of this portion of the tunnel. From this face was taken the sample whose analysis is given below in column 2.

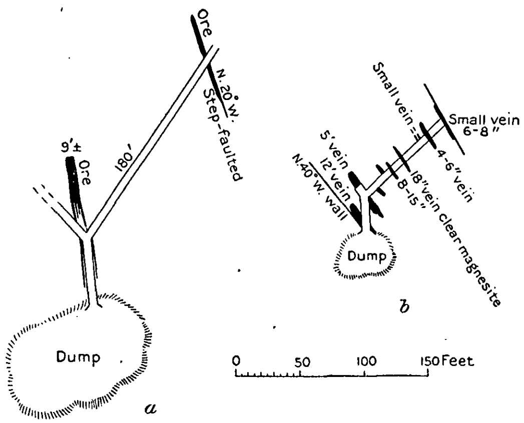


FIGURE 46.—Sections of two main tunnels on lower magnesite claims on East Fork of Austin Creek, Sonoma County, Cal.

At this point a crosscut was started, running off to the northeast about 90 feet farther. There is much minor faulting, but the general trend of the veins is N. 30°–40° W. Besides the larger bodies of magnesite near the entrance, there is another vein about 4 feet thick, faulted and somewhat offset across the course of the tunnel. At several other points veins ranging in thickness from 4 to 18 inches or more have been encountered. At one place a shallow drift has been run to follow a group of several smaller veins, but without much success. Besides the displacement due to minor faulting there is much that indicates lack of continuity of the veins for long distances. The property may, of course, contain other deposits that are not developed in the present workings. It appears that further prospecting on the larger ore bodies themselves is needed to determine the extent of the commercial reserve on this property.

The developments at the upper claims, 1½ miles northwest of the lower claims, consist principally of a tunnel about 100 feet long, driven in on a course N. 48° E., on the east side of the creek about 50 feet above the water and 230 feet below large outcroppings of magnesite which form prominent ledges on the steep slope above. This tunnel has been directed with the intention of crosscutting the magnesite veins but at the time of the writer's visit had not reached them.

The exposure higher on the slope consists of a large projecting ledge of white magnesite, which makes a conspicuous feature in the thickly forested and brush-covered hillside. The thickness and attitude of the ledge are difficult to determine from the present exposure, as an apparent vein-banded structure dipping 40° NE. is most evident in the ledge, and yet the attitude of the extension of this massive ledge to the southeast, as viewed from a distance, is that of a rather steep dip toward the creek, or southwest. For this reason the section measured on the outcrop, giving a thickness of 30 to 35 feet across the banded structure, very likely does not represent the true cross-section of the vein. Magnesite constitutes a very large part of the mass, however, as is indicated by surface exposures, and further underground exploration of the deposit will be necessary before its limits can be more positively defined. The extent of this deposit in either direction is also a matter of much uncertainty. A ledge similar to the magnesite outcrop was observed to the northwest, and evidently the ledge extends about S. 30° E. from the outcrop that was examined above the tunnel. According to report the ledge has been traced 300 feet to the north and 400 feet to the south, but the deposit is supposed to be thickest near the center.

The magnesite of both the upper and the lower claims appears to be of similar character, although no samples for analysis were taken from the upper claims. The outcrop consists of rough and weather-stained rock which it was thought not worth while to sample for analysis, as a sample from such rock probably would not be representative of the deposit as a whole. Where the rock is broken off, the magnesite shows a chalky white surface, in patches having the typical white china-like fracture, but the mass is irregularly broken or jointed and filled with seams and cavities lined with silica. This gives to the deposit the appearance of being unusually high in silica, although this does not seem to be entirely borne out by the analyses of the selected samples taken at the lower claims. Siliceous bands throughout the outcrop stand out on the weathered surfaces, probably making them more conspicuous than they would be in freshly quarried parts of the deposit.

In the following table the first analysis is one made by A. J. Peters on a sample collected by Frank L. Hess, selected to represent the deposit at the time of his examination at the lower claims, and the second is a recent analysis made by Walter C. Wheeler, of the Geological Survey, on an average sample from a working face in one of the tunnels on the lower claims, collected by the writer during his recent examination. This sample represents 60 inches of magnesite cut from the vein of that width exposed in the upper tunnel on the lower claims at the end of the first portion of the tunnel, about 25 feet from the entrance. The sample was chipped, after some preliminary cleaning, across the section of vein exposed in the tunnel and was afterward crushed and quartered. This 5-foot cross-section was the best looking portion of the veins exposed in the tunnels.

Analyses of magnesite from lower claims on East Fork of Austin Creek.

	1	2
SiO_2	7.67	3.66
Al_2O_3	.26	.75
Fe_2O_3	.29	.44
CaO	.04	.20
MgO	43.42	44.90
CO_2	48.08	49.20
Undetermined	.24	.85
	100.00	100.00

Probably the silica in the deposit as a whole would average higher than that shown by the second analysis, and for this reason the writer is of the opinion that the first analysis may be more truly representative of the whole deposit. There is no reason to doubt the representative character of the samples with reference to the other constituents. The magnesite apparently lacks the beautiful white, even-grained texture so characteristic of the better part of other deposits in the State. Lime, commonly considered one of the most detrimental constituents if present in amounts over 1 or 2 per cent, is low or practically absent in the samples analyzed. Iron and alumina are also low, and for refractory purposes at least the silica in the form of quartz or chalcedony is probably not a serious detriment, except that it is an unnecessary constituent and increases the weight for shipment. So far as may be judged by analysis alone the product would also be entirely satisfactory for use in cement, though this inference should be corroborated by practical tests. The quality of the magnesite, as shown by samples from the lower claims alone, is therefore judged to be generally satisfactory.

Prospective development of these deposits is now being pushed. Success in the undertaking naturally will depend on many factors, including skillful management, correct estimates concerning market for the product, moderate costs of production and transportation, and adequate mining facilities, but other considerations that are vital to the success of such an enterprise relate to the quality of the magnesite that can be obtained from the deposit and to the question whether or not the veins are in fact large and persistent or merely erratic deposits.

A glance at the map (fig. 45) will show that important bodies of magnesite have been found at only two localities in this district, and these are known chiefly from the natural outcrops, which are not of very unusual size or character. Some shallow development work has been done, with results that are not entirely satisfactory, so far as affording proof of the size or extent of the deposits is concerned. It is true that certain parts of the deposits are shown by analyses to be magnesite of good quality, but little is known of the continuity of the deposits underground. In fact, such evidence as has been obtained tends to justify the assumption that the ore bodies are of very irregular and uncertain extent, a characteristic that is common to most known magnesite deposits. Large bodies of magnesite have been developed elsewhere and may be developed here. Other conditions being favorable, the deposit undoubtedly warrants a thorough test to determine what may be reasonably counted on as a magnesite reserve.

GILLIAM CREEK.

The deposits of magnesite on Gilliam Creek have been described as some of the most extensive surface exposures in the State. For this reason they were visited by the writer. There has probably been no further development since the property was visited by Hess in December, 1906, and therefore about the only new contributions are the sketch map (fig. 47) and the analysis given below, which by comparison with the former analysis may give some further basis for estimating the quality of the magnesite available.

The deposits are described as including in part lots 3, 4, and 5, sec. 6, T. 8 N., R. 10 W., Mount Diablo meridian, said to be patented and owned by the Western Carbonic Acid Gas Co., of Agnew, Cal. The road leading to the deposits, reported by Hess as under construction in 1906, had at the time of the later visit been long disused and had fallen out of repair so that it was in places impassable with a wagon. From the appearance of the property it is doubtful if any considerable quantity of magnesite has ever been shipped from this place.

The magnesite occurs, as usual, in the form of veins in basic rock partly altered to serpentine. The serpentinous rock is evidently intrusive and is exposed in masses irregularly distributed through the general country rock of sandstones and shales. During the writer's hurried visit, the geologic relations were not worked out in detail, only the fragmentary notes given below and the data presented on the accompanying sketch map being obtained.

The magnesite ledges occur in the more siliceous or more resistant zones of the serpentinous country rock, illustrating the general vein origin of the deposits. Thus the deposits in general lie on or near the summits of ridges, where they have more effectively withstood decomposition and erosion. At this locality the veins may bear some relation to the contacts of the serpentine and sedimentary rocks. It is uncertain whether they are simple vein fillings following shear zones in the serpentine, in which case it might be difficult to account for the large mass of some of the deposits, or fillings of

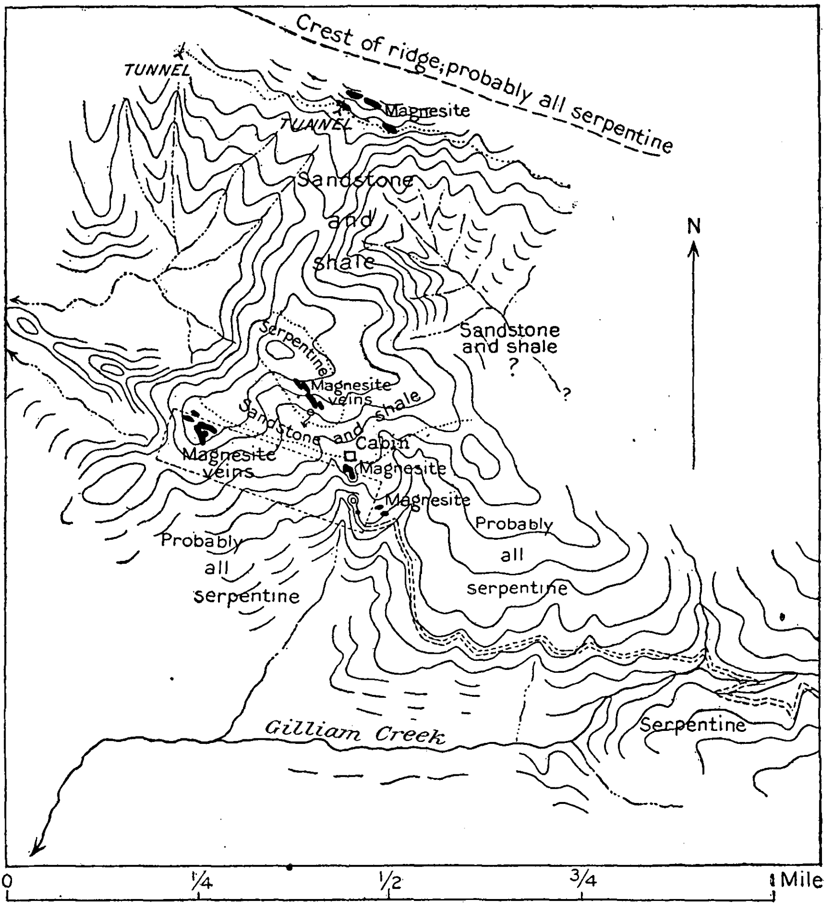


FIGURE 47.—Sketch contour map of the Gilliam Creek magnesite deposits, Sonoma County, Cal.

contraction cracks in the original mass of the serpentine, although it seems more likely that they are in part replacement deposits originating in fissured zones in the serpentinous country rock.

The principal group of claims noted lies just beyond the end of the wagon road built to the property from Gilliam Creek. Here, as in the claims farther north, the principal trend of the deposits is somewhat north of west, although the more prominent outcrops are decidedly discontinuous. Large masses of magnesite, both in outcrop and as float, were observed on the hillside near the end of the road and on the west side of the ridge to the northwest. The stack of material from which the sample for analysis was taken was evidently composed of this float that had been collected for possible shipment. It is not known how far this lode has been traced to the northwest, as no one familiar with the property was there when the visit was made, and time to make a thorough examination of the property was not available. Large blocks of float near the road to the southeast and the sharp, narrow ridge extending to the northwest indicate an extension of the zone of silicification with which the magnesite ledge may also be associated.

The following analyses of magnesite from this deposit include (1) one made by A. J. Peters [1] from a sample selected to be as nearly representative of the rock as possible, and (2) one recently made by Walter C. Wheeler, in the Geological Survey laboratory, representing an average of samples collected by the writer from many parts of the pile below the cabin at the end of the wagon trail.

Analyses of magnesite from Gilliam Creek, Sonoma County, Cal.

	1	2
SiO_2	3.51	10.21
Al_2O_3	1.10	.31
Fe_2O_3	.80	.74
CaO	1.46	.59
MgO	43.65	41.06
CO_2	49.16	44.76
Undetermined	.32	2.33
	100.00	100.00

It will be noted by comparison of these analyses that there is some variation in the two samples, both intended to be representative of the same property. In analysis 2 the silica is much higher than in the earlier analysis. From the general appearance of the rock it is thought that the higher silica content is more nearly representative of the deposit. Silica in a magnesite rock may usually be regarded, for many purposes for which this material is used, as an inert impurity. The low percentage of lime is considered favorable, and iron and alumina are not high.

Nearly parallel to the lodes described, half a mile to the north or northeast, prospects on magnesite ledges were observed in the flank of a somewhat higher and wooded ridge. This locality was not explored in detail, and the work done on the prospects was old and the tunnels caved, so that little accurate information concerning these deposits was obtained. Most of the magnesite seen was float on the hill slope. Some was seen in large masses along the ridge, but it appeared much seamed and banded with silica or foreign matter.

[1] Hess, F. L., op. cit., p. 25.

ECKERT RANCH.

It has been reported that in 1912 two carloads of magnesite were shipped from one of the deposits on the Eckert ranch, 2 miles east of Cloverdale, Sonoma County. It is said that this material was collected from the surface and no attempt is now being made to develop a regular production from this property.

SANTA CLARA COUNTY.

Large deposits of magnesite of great purity at Red Mountain, in T. 6 S., R. 5 E., in the northeast corner of Santa Clara County, along the Stanislaus County line, are said to have been known for a long time, and several attempts have been made to put the property on a producing basis. Red Mountain is one of the higher crests in the Coast Ranges about 60 miles southeast of San Francisco, near the corner of Stanislaus, San Joaquin, Alameda, and Santa Clara counties. The deposits are probably among the best in California.

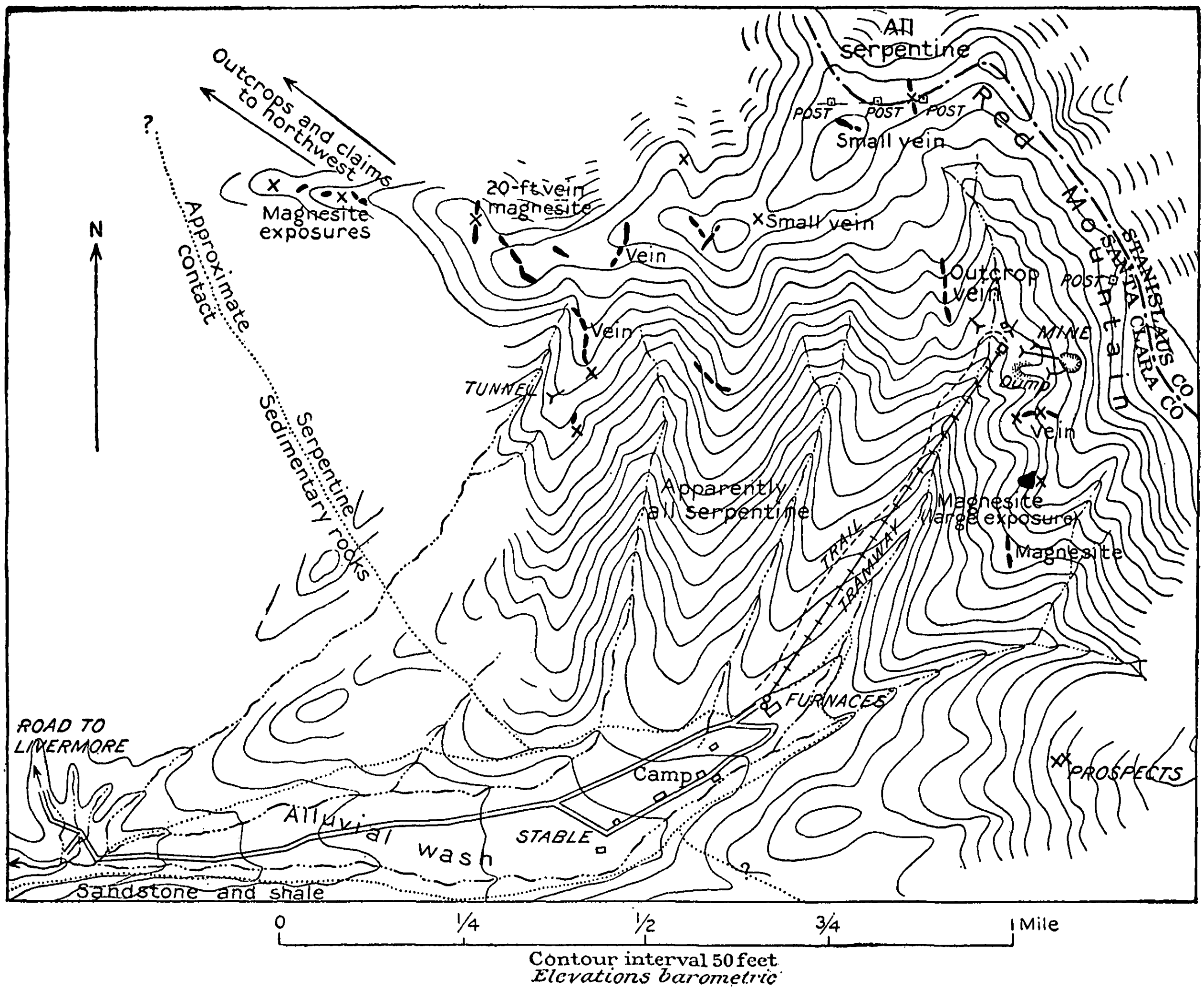
Livermore, the present shipping station, is about 32 miles distant over an excellent graded road that follows the valley of Arroyo Mocho southeast from Livermore, rising from an elevation of 487 feet at the Livermore station to a summit of nearly 2,700 feet, thence descends and crosses Colorado Creek at the head of Arroyo del Valle, and passes over another summit into the basin in which the deposits are situated.

It is stated that the deposits were first worked in 1905. A well-equipped plant, including two furnaces of the stack type, a warehouse, and camp buildings are situated in the valley below the mine and prospects and are connected with the main workings by a 3,000-foot tram which has a vertical drop of about 550 feet. The camp has a good water supply, which is derived from springs and which, though small, seems to be ample to meet the requirements.

At the time of the writer's visit (September 13 and 14, 1912) the property was being worked in a small way, magnesite being extracted to be shipped to San Francisco for the manufacture of a waterproofing paint for concrete and brick.

The deposits are covered by a group of 12 or more lode claims, but one of which, it is understood, had been patented. The outcrops prospected or mined lie on the southern and western slopes of Red Mountain. The ledges of the chalky-white magnesite stand out conspicuously as viewed from the valley, forming a contrast against the dark reddish-brown soil which covers most of Red Mountain and from which it probably takes its name. The whole mountain area is more or less thickly covered with scrubby brush, chiefly manzanita.

The general area containing the magnesite outcrops is occupied by serpentine without evidence of much variation in character or of



SKETCH CONTOUR MAP OF MAGNESITE DEPOSITS AT RED MOUNTAIN, SANTA CLARA COUNTY, CAL.

inclusions of other rocks. The serpentine is bordered on the west by sedimentary sandstones and shales which form a distinctly different topography. The other limits of the mass of serpentinous rock have not been defined. The original country rock from which the serpentine is derived is described by Hess[1] as lherzolite and peridotite, in some places remarkably fresh. Lherzolite is a variety of peridotite and is composed essentially of the minerals olivine, diopside, and an orthorhombic pyroxene. The mineral serpentine is a natural alteration product from such rocks. The original country rocks are composed principally of silicates of magnesia (silica 40+ per cent; magnesia 25 to 40 per cent; alumina and iron variable, usually 5 per cent or more; and a small percentage of alkalies). It is natural to assume that magnesite might be derived by the decomposition or alteration of these silicates being deposited as veins along fissured zones or by replacing the country rock. As a whole, however, the serpentine of this area does not show the excessive amount of shearing to be seen at many of the other magnesite localities.

Throughout the dark-red soil that covers the area of serpentine country rock, especially in the zones that contain the magnesite veins, silica is present in various forms. It occurs in part as a white and rosiny opal, scattered fragments of which are strewn about on the surface, or it may be observed as chalcedonic veins or coatings in the joints of the country rock. The silica associated with the purer mass of magnesite in the larger pit was in the form of a pale-greenish granular quartz.

The magnesite veins are very irregularly distributed and appear to trend in all directions. The larger developed masses are of most unusual size, and even the great bodies that have been removed by mining have been taken out in large open caves or chambers, so as to give little evidence of the real extent or size of the deposits underground beyond that which has been taken out. It appears that the amount of magnesite available must be very large, and as it is situated under favorable conditions for mining it should constitute, if properly handled, one of the most profitable deposits in the State whenever the market can be developed to support a steady domestic production.

The accompanying map (Pl. X) was made by pacings, with the use of a pocket compass, the elevations being obtained from an aneroid barometer. It is therefore not exact, nor is it supposed to represent all the outcrops of the magnesite or all the prospects. It indicates the distribution and irregular trend of the larger veins observed and shows the situation of the mine and camp and the approximate contact of serpentine and sedimentary rocks on the southwest side of the deposits.

[1] Op. cit., p. 34.

In general the magnesite veins seem to be distributed through a belt having a northwest-southeast trend. Claims and prospects on the magnesite some distance to the northwest beyond the limits of the area mapped could be distinctly seen but were not visited.

A number of the large outcrops of magnesite are situated on the higher slopes of Red Mountain, facing west and south on the headwaters of streams draining toward the south and southwest, so that the material from nearly all the deposits may be very conveniently carried by trams or otherwise as far as the valley flat in which the camp is situated. The main workings consist of a number of tunnels and an open cut near the head of the tram. From this place the magnesite that has been shipped was taken out. The principal tunnels run in on two levels, encountering a large body of pure white magnesite, from which a considerable amount has been removed. A large stope in the underground workings measures about 30 by 30 by 60 feet, all in magnesite of almost unusual whiteness and apparent purity, and this vein is also represented at the surface by a large open pit or "glory hole" 40 yards or more in length and 25 to 30 yards wide in its widest part, with a cavelike excavation beyond. Much of the pit has been excavated in thoroughly shattered and decomposed serpentine, but the area has contained large bodies of good magnesite, portions of which show on the sides of the pit and in the cavelike excavation at its southeast end. The magnesite includes some seams and bands of silica, in part a greenish granular quartz or chalcedony and in part a clear whitish opal, but it is a very minor constituent of the mass. Toward the borders of the large masses that have been removed the magnesite becomes more and more mixed with the serpentinized country rock, so that it is difficult to define the limits either of the magnesite body or of the purer part. The serpentine adjoining the large magnesite masses is softened, almost earthy, and of a dull yellow-greenish color and is filled with thin seams which contain magnesite and silica. The coarser joints that traverse the country rock are commonly stained a deep red, as if by iron derived from the soil above. The roofs of the large stopes or cavelike openings cut in solid massive magnesite stand without timbers or other support.

There are a number of other prospect pits, shafts, and exploratory tunnels on the different exposures about the property. These are partly indicated on the accompanying map (Pl. X), but it is difficult to give much detailed information about unopened deposits in the absence of careful sampling and analytical data. Many large veins are exposed at the surface, apparently containing a considerable reserve of magnesite of the excellent quality similar to that shown in the body that has been worked. Several ledges expose veins 10 to 20 feet or more in width at the surface. There seems to be little doubt that the property contains large resources in magnesite, even though comparatively little is known about the underground extension of the deposits.

The following analysis of the magnesite from Red Mountain is quoted from Hess[1] and was made on a single specimen selected to be representative of the average of good material taken from the deposit. No samples for analysis were collected by the writer.

Analysis of magnesite from Alameda claim, Santa Clara County, Cal.

[A. J. Peters, analyst.]

SiO_2	0.73
Al_2O_3	.14
Fe_2O_3	.21
CaO	.40
MgO	46.61
CO_2	51.52
Undetermined	.39
	100.00

PLACER COUNTY.

Deposits of magnesite have long been known in Placer County, and newspaper notices have from time to time been published, presumably in the effort to draw attention to them. These notices refer more particularly to some outcrops that have been located in claims described as situated in sec. 18, T. 15 N., R. 11 E., on the upland south of the American River canyon about midway between Iowa Hill and Damascus. The report received to the effect that one new mine had been opened at Iowa Hill in 1911 and a few hundred tons of magnesite extracted, none of the product being shipped or calcined, has not been substantiated.

The geology of the area as a whole is described by Lindgren.[2] The area lies within the great forest zone of the Sierra Nevada. The upland surfaces constitute in general form a gradual westward slope from the crest of the Sierra, which is deeply intrenched by stream canyons that form a rugged and picturesque topography but render much of the area difficult of access. The magnesite claims west of Iowa Hill are thus unfavorably situated for the transportation of any bulky or heavy material like magnesite, as it is at present necessary to descend into and cross the canyon of American River to reach them from the railroad. Colfax is now the most favorable point of access and from it the Iowa Hill road descends to American River, a drop of 1,300 feet in about 2 miles, and rises on the east side in an even shorter distance. The distance by road from Colfax to the deposit is about 12 miles, and it would probably take five hours with a light buggy and good team to make the trip.

[1] Op. cit., p. 36.

[2] Lingren, Waldemar, Colfax folio (No. 66), Geol. Atlas U. S., U. S. Geol. Survey, 1900.

The occurrence is, however, of interest and the possibility that the magnesite in this vicinity may at some time become of commercial importance must be recognized. The magnesite veins are, as usual, associated with a country rock of serpentine, a large area of which lies between Iowa Hill and Damascus. This belongs to the great serpentine belt described by Lindgren as follows:

Through the center of the Colfax quadrangle, from north to south, extends a broad belt of igneous rock surrounded by Carboniferous sedimentary rocks. It consists very largely of serpentine, from which feature the miners have called it the great serpentine belt. It is, however, a very complex area, made up of many basic rocks rich in magnesia, the most prominent of which are gabbro, peridotite, and diorite. Partly

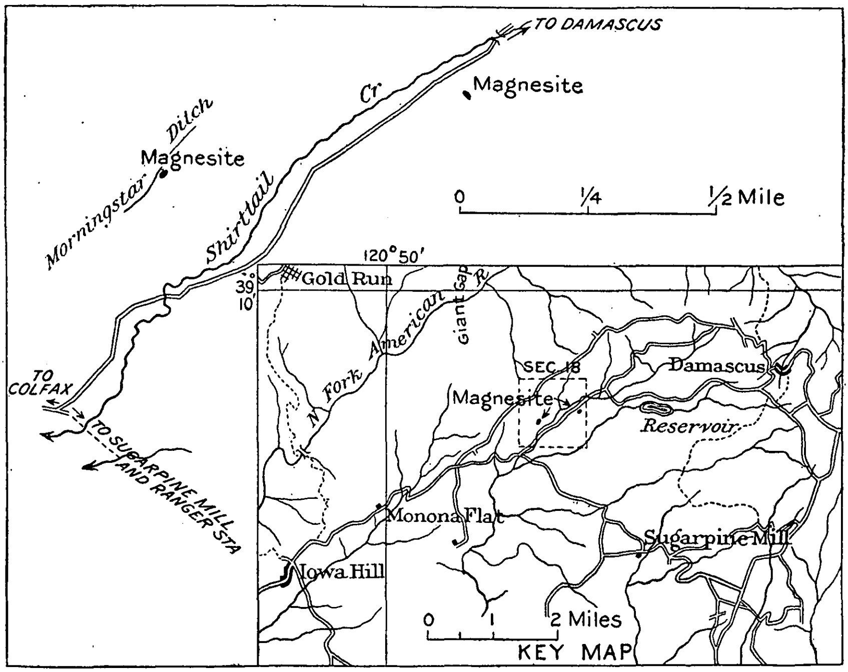


FIGURE 48.—Map showing relative location of the magnesite veins examined in the vicinity of Iowa Hill, Placer County, Cal. (Adjustment of sec. 18 approximate only.)

serpentinized peridotite has so often been found in the serpentine as to justify the belief that most of the latter rock has resulted from the alteration of peridotite, though it would perhaps be going too far to say that all of the serpentine had this origin. * * *

The great serpentine belt, extending through the Placerville, Colfax, and Downieville quadrangles, is apparently a continuous dike intruded in the Carboniferous sedimentary rocks, sometimes following, sometimes cutting across their strike.

The location of the deposits visited is shown by the accompanying map (fig. 48). By comparison with the description of the deposit quoted by Hess[1] the veins found by the writer are evidently the ones referred to in that description, except that no single body 30 by 100 feet was seen.

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[1] Op. cit., p. 52.

Outcrops of magnesite at two localities were visited. The western occurrence is near and below a large ditch on the north side of the reservoir road to Damascus, east of the fork to the Sugarpine mill. The outcrop appeared to represent lenses and small veins, none of those examined exposing any considerable body of ore. The area is thickly timbered, and it is possible that not all the known outcrops were found. There was an old pit but no evidence of recent work. The veins in places measure a foot or more in width and the magnesite is largely mixed with serpentine, which is the country rock. All the veins appear discontinuous. Some portions of the veins contain clear-white magnesite with conchoidal fracture.

The other exposure examined lies south of the road, a little over half a mile somewhat north of east from the outcrop just described. At this place there was no evidence that any work had been done. The ledges are on the timbered hill slope and contain some good clear-white magnesite, with china-like fracture. The country rock is all serpentine and so far as observed is continuous between the two deposits. From one of the ledges 2 feet thick a sample was collected by chipping fragments on a freshly broken surface across the accessible part of the vein. The sample represents about 1 foot of the 2 feet or more exposed and evidently contains material of good quality. The analysis is as follows:

Analysis of magnesite from Placer County, Cal.

[R. C. Wells, analyst.]

SiO_2 $(Al, Fe)_2O_3$	0.2
CaO	None.
MgO	47.3
CO_2	51.6
H_2O	0.6
Undetermined	0.3
	100.00

In both localities the exposures are comparatively small, covering probably not over 20 or 30 square feet of rock in place, and while such outcrops might lead to larger bodies underneath, the few and scattered veins that are known do not offer much encouragement. The present cost of hauling from such a locality would prohibit the shipment of material of the value of magnesite, and it seems doubtful if much can be done with these deposits until better transportation facilities are offered.

SAN BENITO COUNTY.

In 1911 new deposits of magnesite on Larious Creek, in San Benito County, Cal., were reported to C. G. Yale, in the San Francisco office of the Geological Survey, by Hugo Fischl. In February, 1912, through the courtesy of Mr. Fischl, the writer was enabled to make a brief visit to these deposits and a short account of them was published in the annual statistical chapter on magnesite.[1] Later in the year (September, 1912) a second visit was made to the same deposit, which resulted in some hasty traverse sketch mapping and the collection of further specimens for analysis and study.

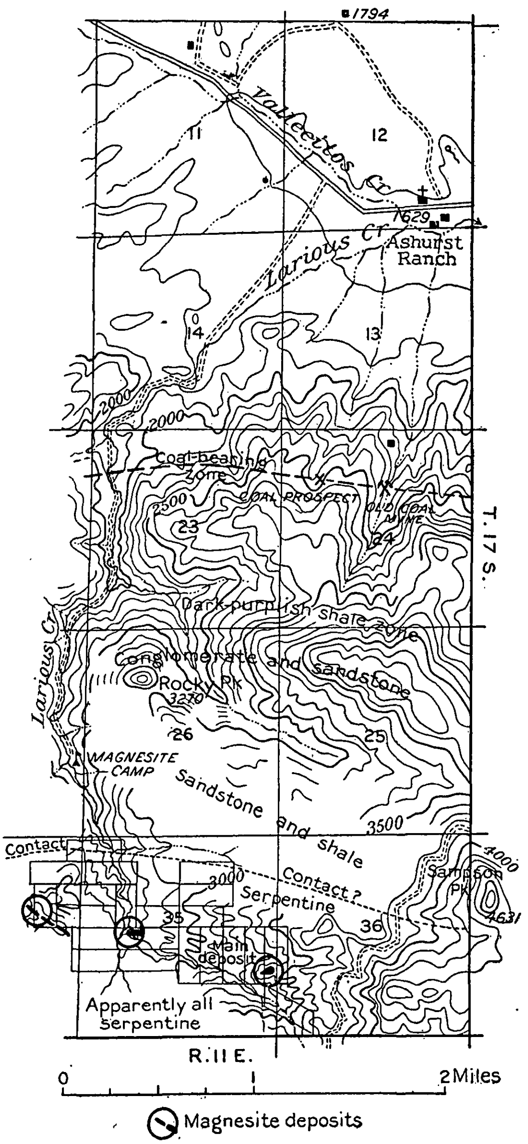

FIGURE 49.—Incomplete contour map showing location of Sampson magnesite lode claims, San Benito County, Cal.

The deposits on Larious Creek are mostly covered by a group of 21 claims known as the Sampson magnesite lode claims, owned by R. H. Moore and Hugo Fischl. The principal exposure, supposed to contain the largest body of the best ore at present revealed in the district, lies on the east side of Larious Creek. There are a number of other veins or deposits ranging from those carrying magnesite of the better quality to silicified shear zones containing magnesite mixed with the serpentine country rock. The exposures as a whole are extensive.

The location of the deposits is given as secs. 34, 35, and 36, T. 17 S., R. 11 E. Mount Diablo meridian. The approximate location of the claim group is shown on the map (fig. 49). The deposits are situated a little over a mile west of Sampson Peak and about 2½ miles west of the New Idria quicksilver mine, in the steep slopes of the Diablo Range. Most of the outcrops lie on the slopes in the upper valley of Larious Creek, a tributary of Vallecitos Creek.

[1] Mineral Resources U. S. for 1911, pt. 2, U. S. Geol. Survey, 1912, pp. 1113-1127.

The deposit is 35 to 40 miles from the nearest railroad station, Mendota, in the San Joaquin Valley.

The geology of this district is discussed in some detail in a bulletin by Anderson and Pack,[1] which deals primarily with the oil prospects in the region. The large area of serpentine exposed along the high parts of the Diablo Range in this vicinity is believed to be an intrusive mass of batholithic form, which occupies the crest of a major anticlinal axis in the sedimentary strata within which it is included. The original rock has now been so largely altered to serpentine that the whole mass is commonly referred to as serpentine. This is the type of rock with which California magnesite deposits are generally associated, and evidently it bears a genetic relation to the magnesite.

An excellent section of the sedimentary strata associated with the serpentine at this place, ranging from the sandstones and shales of the Franciscan formation to the later Tertiary formations, is exposed in the valley of Larious Creek, but details of the geology of those beds are not supposed to have any bearing on the magnesite or the matter of its commercial exploitation. It is possible that the occurrence of a bed of coal not far distant might ultimately have some effect upon the reduction or transportation of the magnesite, but there is probably greater likelihood that oil as fuel would replace the light subbituminous coals found in this vicinity. The locations of some of the coal prospects are shown on the map (fig. 49), together with an indication of the approximate tracing of the outcrop of the coal-bearing zone.

The outcrop of the principal magnesite ledge is a broad exposure about 500 feet in length and covering 2.6 acres (survey by E. Halloran for the magnesite company). (See fig. 50.) The main deposit, as shown on figure 49, is situated on the summit of a high spur that extends west from Sampson Peak, between two forks of Larious Creek. The main crest of the ridge is on the surface composed entirely of white massive magnesite, and on the west end the deposit has the appearance of being a steeply dipping vein in the serpentine country rock, trending about N. 70° E. The eastern part of the summit flattens out so that the outcrop ledges of magnesite on the top appear to be possibly in horizontal or "blanket ledge" form. If the deposit continues in depth with horizontal dimensions corresponding to those at the surface, it is of immense size. A report received since the last visit by the writer states that a prospect tunnel has been driven from the south to undercut the deposit on the broad east end of the deposit, and the approximate location of this tunnel is plotted in figure 50 from the description of

[1] Anderson, Robert, and Pack, R. W., Geology and possible oil resources of the western border of the San Joaquin Valley, Cal., between Coalinga and Livermore Pass: Bull. U. S. Geol. Survey (in preparation).

locations given in the report. Statements of the results obtained in driving this tunnel seem to indicate that the ledge is of blanket form on the east end of the deposit, but that the body of magnesite has considerable thickness there. Details of the working are not now available. Of those now known this deposit contains the greater part of the highest-grade magnesite on the property, and there is a possibility that further work will show that some of the smaller supposed outcrops farther down the hill slope are but broken masses slid down from this deposit.

Outcrops of the better hard magnesite are in the main exposed in massive ledges, which are resistant to weathering and commonly stand out prominently, capping ridges that they have protected from erosion while the adjacent softer rocks have crumbled and been

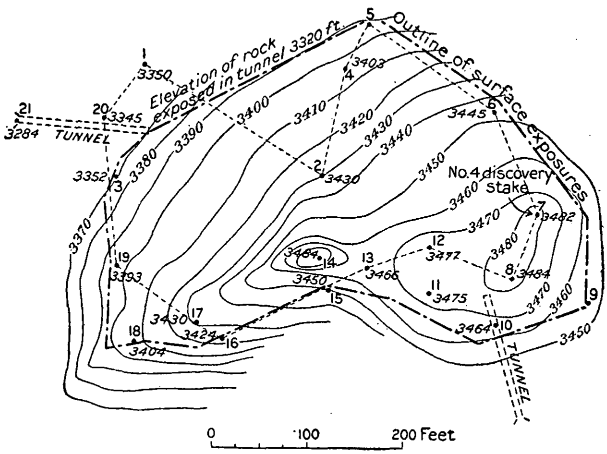

FIGURE 50.—Main deposit of Sampson magnesite lode claims, San Benito County, Cal. Elevation datum approximate. Published by permission of Mr. Hugo Fischl.

carried away. The white, weather-rounded surfaces of the magnesite show the solvent action of rain or surface waters, being in places sharply fluted, more or less covered with moss and lichens, and stained in spots with a yellowish-brown to rusty color. The inside of freshly broken pieces is generally white, but in places a pale-yellow stain extends into the rock to a depth of several inches from the exposed surface or along joints and cracks. When freshly quarried the whole mass of the rock would be characteristically white in general aspect, just as the outcrop now appears from a distance. Some cracks or cavities in the magnesite contain silica, generally in chalcedonic form, and this is usually colored a pale green, as if by some form of chromium. Much of this green chert-like material is to be found in association with other impure siliceous veins on the adjoining hillside.

A very prominent ledge of an impure siliceous and iron-stained magnesite forms the crest of a peak on the west side of Larious

Creek, approximately on the line between secs. 34 and 35. This is evidently a zone of silicification and secondary deposition, the magnesite material being included within the serpentine mass, which has a trend of N. 60° W. and an apparent northeasterly dip of about 70°. The outcrop is very yellow and iron-stained and stands out in rough crags, being evidently a vein at least 20 feet thick. Its extension to the southeast is marked by outcrop ledges which form the summit of a ridge leading off toward the upper Larious Creek valley. As a whole the impure character of the rock is supposed to render this large deposit of doubtful value, but it remains to be seen whether such a rock will find a use for refractory or other purposes. Smaller masses of purer white magnesite are included within the vein, but none of the bodies observed in outcrop were of sufficient size to be workable.

Similar iron-stained siliceous veins or silicified shear zones containing some magnesite are found in the serpentine on the slopes and ridges leading up to Sampson Peak. Most of these have not been prospected and are of doubtful value. One of the most prominent is indicated on the map east and northeast of the main magnesite deposit. At places these rusty honeycombed outcrops of silica and other rock resemble the gossan of a metalliferous lode.

Analyses of the rock from these deposits have been made as follows: A single block broken from the exposure at the main deposit at the time of the writer's first visit was analyzed in the Geological Survey laboratory by J. G. Fairchild, and the analysis is given as No. 1 in the following table. No. 2, made by W. B. Hicks in the Geological Survey laboratory, is the analysis of average material made up from twelve samples taken at points distributed over the large outcrop on the crest of the ridge. This is believed to represent the average character of the deposit as nearly as was feasible under the existing conditions. Before sampling the weathered surface was cleaned by chipping so as to eliminate if possible surface stain and alteration. No. 3, also made by W. B. Hicks, is the analysis of an outcrop sample of magnesite taken from the ledges of iron-stained siliceous rock on the west side of Larious Creek. It is doubtful whether this sample is representative of the whole deposit.

Analyses of outcrop samples of magnesite from San Benito County, Cal.

	1	2	3
SiO_2	0.14	0.81	11.08
Al_2O_3	.48 (with Fe_2O_3)	.00	.55
Fe_2O_3		.52	.61
CaO	.59	1.04	.60
MgO	47.07	46.67	41.38
CO_2	50.66	50.60	45.26
Undetermined	1.06	.36	.52
	100.00	100.00	100.00
Loss on ignition	....	51.43	46.10

Analyses 1 and 2 indicate that the magnesite of the main deposit is of somewhat exceptional purity, the silica, iron, alumina, and lime being so low that the rock is believed to be available for either cement or refractory products.

One other feature of the district deserves special comment. In the forks of Larious Creek, near the center of the W. ½ sec. 35, there are large wash banks of slide material wholly bare of vegetation, forming a striking contrast to the brushy and scrub-timbered slopes that surround them on all sides. These slides are somewhat weather-stained at the surface but have a white limy appearance in excavations or fresh breaks. The material is a much-sheared serpentine, fresh samples of which range from a dull green, earthy color to the clear green of the mineral serpentine in polished slickensided surfaces. Throughout the mass a white powdery mineral occurs in specks and in little rounded balls. These are readily effervescent and soluble in hydrochloric acid and are indicated by analysis No. 2, below, to be hydromagnesite. In the following table No. 1 is the analysis of a sample from the surface in this slide deposit as it occurs, including the sheared serpentine and some hydromagnesite, and No. 2 is an analysis of the white powdery hydromagnesite, made from a large number of the little balls picked out from the weather-decayed mass at the exposure. Both analyses were made by W. B. Hicks in the Geological Survey laboratory at Washington.

Analyses of weather-decayed serpentine and hydromagnesite from forks of Larious Creek, Cal.

	1	2
SiO_2	35.24	2.50
Al_2O_3	.38	.13
Fe_2O_3	7.08	.44
CaO	.20	.34
MgO	39.35	41.60
CO_2	2.66	34.89
Undetermined	15.09	20.10
	100.00	100.00
Loss on ignition	18.15	54.10

The main deposit, situated on the slopes of Sampson Peak, unquestionably contains a large body of high-grade magnesite, and by careful measurements of it a fair estimate of the available material in sight could readily be made. It is to be expected that eventually, when the transportation problems for this district have been solved, and when a market for high-grade domestic magnesite from California has been developed to support a continuous production from such deposits, this will prove to be one of the more valuable deposits in the State.

As to the extent and possible utilization of the hydromagnesite deposits in the forks of Larious Creek or of the siliceous deposits on the west side of Larious Creek and elsewhere near the main deposit on the slopes of Sampson Peak, it hardly seems necessary at present to venture any prediction, for these are matters to be proved by practical trial. The analyses given in the present report may serve as some basis for estimating the availability of these materials for other uses.

FRESNO COUNTY.

Magnesite has been observed in the eastern foothills of the Diablo Range in the vicinity of the deposits described above. Whether of economic importance or not, this occurrence furnishes interesting data as to the age and possibly indications as to the former distribution of such deposits. The following memorandum is quoted from a manuscript by Anderson and Pack:

> In the middle of the exposed Tertiary rocks skirting the western border of the San Joaquin Valley, about 15 miles east of New Idria, there is a series of beds ranging in thickness from less than 50 feet to several hundred feet, composed almost entirely of comminuted serpentine and of serpentine bowlders. They are of lower Miocene age and probably represent a near-shore marine deposit. They go by the name of the Big Blue. The beds extend for a distance of about 20 miles along the foothills and lie directly east of the large mass of serpentine that is intrusive into the Franciscan rocks in the core of the range south of New Idria. The débris forming these beds has evidently been derived from that mass and has been carried by streams at least 10 miles.
>
> At several places the Big Blue contains fragments of pure hard magnesite a few inches in diameter. They were noticed especially just south of Cantua Creek and between Cantua and Salt creeks, in the patches of these beds that have been left as remnants overlying the older formations. The fragments are in places scattered over the surface at intervals of a few hundred feet. They are without question of the nature of bowlders derived by erosion from the serpentine area. They are not believed to represent an accumulation in any commercial quantity, but are mentioned only because they point to the presence of magnesite in the serpentine area on the west and prove that at least some of the magnesite veins originated in or prior to the early Miocene.

TULARE COUNTY.

PORTERVILLE.

The magnesite deposits 4 miles northeast of Porterville, which had been mined continuously since 1901, were abandoned in 1909. From 1902 to 1909 these deposits were operated by the Willamette Pulp & Paper Co. They doubtless still contain much workable and valuable magnesite, but the upper parts of the larger vein have been almost completely worked out. Any further development at this place would doubtless have to be made through new entries opening the deposit on lower levels in the vertical vein. There is a considerable quantity of magnesite remaining in the flat-lying vein on this property, but this vein is difficult to work without timbering, which will make mining in this deposit more expensive than the methods formerly employed. A complete description of the Harker magnesite deposits, with a map and illustrations, is contained in Hess's report.[1] The entire equipment, including the furnace, has now been removed from the property.

SOUTH FORK OF TULE RIVER.

A hitherto undeveloped deposit on South Fork of Tule River, 9 or 10 miles east of Porterville, was opened in 1907 by the Tulare Mining Co., of which W. P. Bartlett is superintendent. The deposits were fully described as outcrops by Hess [2] before any development or even prospecting had been done on them. To this description of the outcrops there is little to be added, and the following paragraphs relate principally to the recent developments for the commercial production of the magnesite.

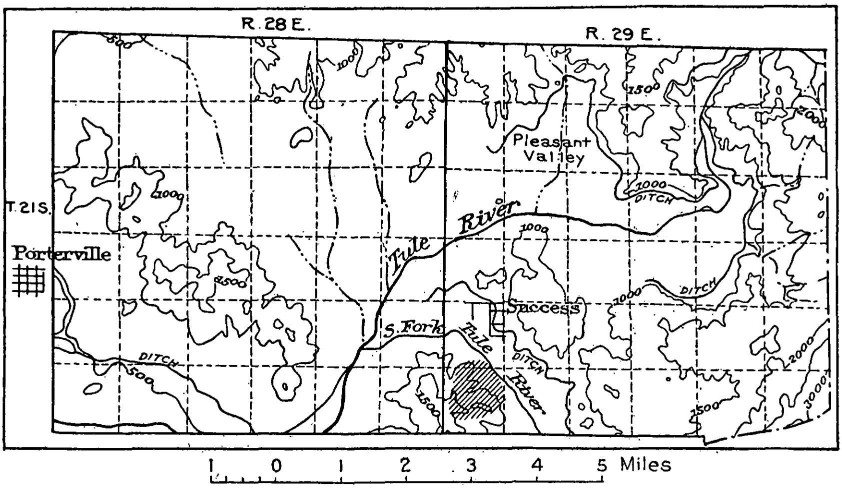

FIGURE 51.—Index map showing location of magnesite deposits on South Fork of Tule River, east of Porterville, Cal.

The magnesite veins are situated on the north face of a high hill southwest of South Fork of Tule River in secs. 30 and 31, T. 21 S., R. 29 E. (See fig. 51.) The Porterville Northeastern Railroad has now been completed along the main valley of Tule River, and a spur about 2 miles long direct to the magnesite deposits has also been built.

Recent mining developments on the deposits consist of a 1,400-foot tunnel through the point of a ridge, not far above water level, some other short tunnels, and many small and large open cuts and pits, by which the numerous other outcrops on the property have been prospected. The 1,400-foot tunnel follows an exceedingly irregular vein, which in places reaches apparently large dimensions

[1] Hess, F. L., Magnesite deposits of California: Bull. U. S. Geol. Survey No. 355, 1908, pp. 40–46.
[2] Idem, pp. 46–48.

and elsewhere is lost altogether. Crosscuts appear to reveal some large bodies of magnesite and in places these bodies are mixed with country rock or foreign matter that probably reduce the quality. At the present stage of development it is somewhat difficult to estimate the reserve on this property, but it is believed to be rather large. No samples of the raw or calcined product were obtained for analysis owing to lack of time when the examination was made.

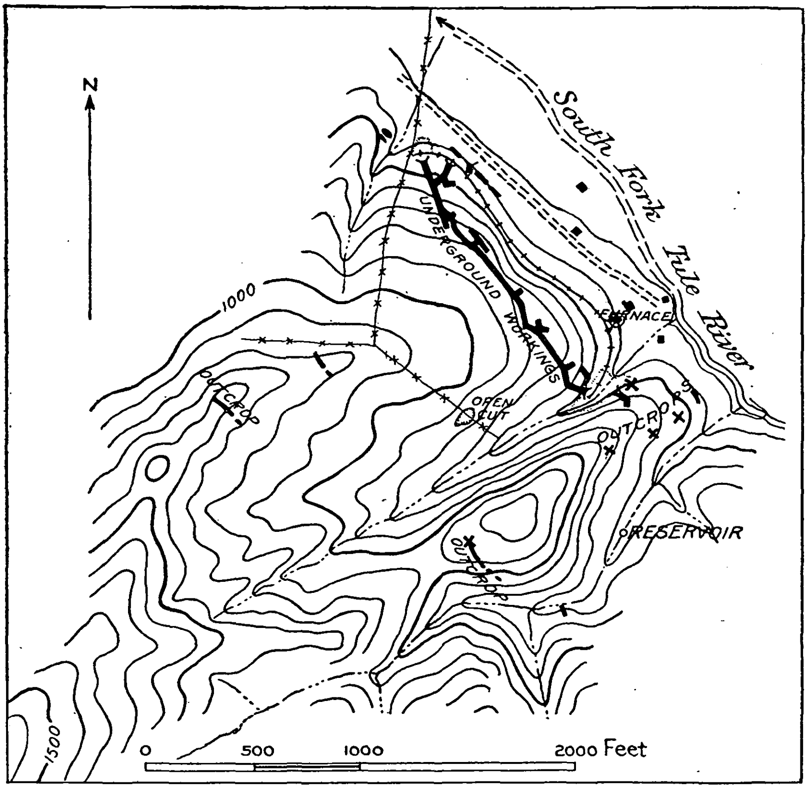

FIGURE 52.—Sketch map of magnesite deposits on South Fork of Tule River east of Porterville, Cal.

No raw rock is shipped, all the product being calcined in stack furnaces at the mine.

The accompanying plat (fig. 52) is the result of a hurried sketch traverse of the property, made February 25, 1912, and although it is not based on an accurate instrumental survey and is not complete, it will serve to indicate the character and relation of both the developments and the more prominent outcrops.

Much of the information here given concerning the production and development of the deposits was obtained through the courtesy and assistance of Mr. W. P. Bartlett, superintendent of the Tulare Mining Co., at Porterville.

KERN COUNTY.

In 1911 a new deposit of magnesite was developed near Bissell station, on the Atchison, Topeka & Santa Fe Railway 11 miles east of Mohave, Kern County, Cal. It is said to have been located in part by B. M. Denison, of Tehachapi, and D. S. Clark, of San Pedro, Cal., and in part by C. A. Williams and J. N. Conover, both of Tehachapi, Cal.

The deposit is situated about one-half to three-quarters of a mile northeast of Bissell station (fig. 53). The only developments that had been made up to March 8, 1912, consisted of a series of pits and a few shallow shafts opening the deposit through a stretch of about a quarter of a mile.

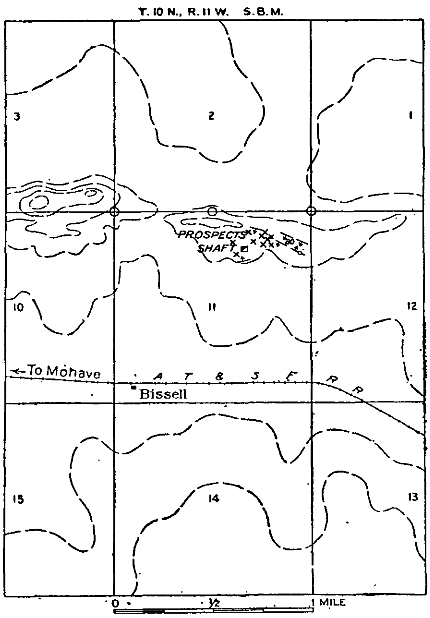

FIGURE 53.—Sketch map of magnesite deposits at Bissell station, near Mohave, Cal. By Leon J. Pepperberg, geologic department, Southern Pacific Co. Contours have only sketch value.

This deposit is unique in being the only occurrence of magnesite of evident sedimentary origin that has been reported in this country. Some deposits in Quebec are described as probably of sedimentary origin, but hitherto all the California magnesite has been described as associated with and evidently derived from altered basic intrusive igneous rocks carrying a large percentage of magnesia.

The magnesite at Bissell occurs in definitely bedded form, interstratified with clays and clay shales and evidently forming a part of the same series that shows massive ledges of limestone and cherty layers in outcrop near by. The clay beds are prevailingly dull greenish but in places consist of a very dark carbonaceous material. In the low rounded hills that characterize this part of the Mohave Desert the strata in general do not outcrop conspicuously and consequently are not readily traced. The limestone and cherty ledges are visible, however, and recent prospecting has revealed the softer magnesite-bearing beds to some extent. The outcrops prospected occur on the south slope of a low ridge.

The dip of the beds is steep and in most places is inclined to the south but in others is practically vertical. The beds are very irregular in trend and, in fact, are locally so much contorted that it was not possible to determine from the surface indications the structural relations between strata exposed in closely adjacent prospect pits.

The following sections—partly measured, partly estimated—serve to indicate the character and thickness of the beds of magnesite and associated materials. The exposures given in these sections afford what is regarded as sufficient evidence of the original bedded character of the deposits. The extreme irregularity of the beds in some of the pits is thought to be due chiefly to structural distortion, and it is not known how constant the magnesite strata may prove to be.

Section at 14-foot shaft near west end of Bissell prospects.

[Some magnesite at top not included.]	Ft.	in.
Cherty layer		6
Clay, carbonaceous, lenticular, about		4
Magnesite, white, about		5
Clay, gray, about		3
Magnesite, white, about		6
Clay, dark gray		4
Magnesite, white		4
Clay, white (magnesite?)		8
Magnesite, clear white, massive	1	6
Clay, brown		4
Magnesite, white, about	1	
Clay, greenish, about		3
Magnesite, compact white		10
Clay (considerable body).		
	7	3

A sample for analysis (No. 4 in the table below), taken at this place consisted of selected pieces of the hardest and whitest magnesite-like rock from the dump, and was intended to represent the best of this ore near the surface.

The beds exposed in this section are largely lenticular in their thicker parts. They also show slip planes and are not uniformly as distinctly bedded as at other points in these deposits. The strike at this place was recorded as N. 15° W., which is almost directly transverse to the trend of nearly all the other exposures throughout the prospected ground. The dip is 60° E.

About 300 feet west-northwest of the 14-foot shaft is a prospect hole 2 feet deep showing dark-brown carbonaceous beds interstratified with pure-white magnesite, one bed of magnesite being at least 15 inches thick. The strike here is N. 60° W. and the dip 45° S.

About 450 feet a little north of east from the same shaft is a hole 12 feet deep showing two rather thin beds of apparently good solid white magnesite. About 700 feet northeast of this shaft is a trench showing several 6 to 8 inch beds of what is supposed to be good white magnesite, interstratified with greenish clay shale.

About the same distance from the shaft and 150 to 200 feet southeast of the locality last mentioned is a prospect trench showing the following section:

Section in prospect trench near Bissell station.

	Ft.	in.
Magnesite		7
Clay, brownish		1
Magnesite	3	
	3	8

An average sample (No. 1 in the table) was cut across the entire face represented in the foregoing section except the 1-inch bed of brownish clay, which readily splits from the magnesite beds. The lower part of the 3-foot magnesite bed contains some thin clayey streaks, 3 or 4 inches to 8 inches apart, which were included in sampling. This was a shallow pit that had been dug very recently and made a very good showing of white hard magnesite in regularly bedded form. The strike here is N. 80° W. and the dip 25° S.

Sample No. 2 represents a 6-inch layer of white clay overlying the section from which sample No. 1 was taken and was saved to be tested for magnesia. The analysis shows it to be of essentially the same composition as the underlying magnesite beds.

Sample No. 3 consists of selected pieces of the best-looking magnesite from the same place as sample No. 1.

The analyses of these samples are given below. They were made in the laboratory of the Geological Survey at Washington by J. G. Fairchild.

Analyses of samples of magnesite from Bissell, Cal.

	1	2	3	4
SiO_2	9.64	8.51	6.03	4.75
$Al_2O_3 + Fe_2O_3$	2.46	2.94	1.40	.76
CaO	4.25	3.36	1.56	Trace.
MgO	37.19	38.32	42.78	44.20
CO_2	40.70	40.12	45.78	47.32
Undetermined	5.76	6.75	2.45	2.97
	100.00	100.00	100.00	100.00

In the foregoing analyses it may be seen that, except in No. 1, carbon dioxide is not present in sufficient quantity to satisfy the magnesia alone if it were all combined as normal magnesium carbonate, even neglecting the fact that the lime is as likely to be in the form of carbonate as the magnesia, and might be combined with some of the carbon dioxide. Theoretically pure magnesite is composed of 47.6 per cent of magnesia plus 52.4 per cent of carbon dioxide. It is probable that part of the silica in this sedimentary material is free and that some of it is combined with lime and magnesia to form silicates. F. W. Clarke suggests the possible presence of basic carbonates, such as hydromagnesite ($3MgCO_3Mg(OH)_2+3H_2O$), which would tend to compensate the proportions, by the relatively smaller amount of carbon dioxide required in its composition.

Another prospect about 750 feet a little north of east from the 14-foot shaft shows the following section:

Section at prospect near Bissell station, Cal.

	Ft.	in.
Magnesite		4
Clay, thin streak.		
Magnesite		2
Clay, thin streak.		
Magnesite		2
Clay (with thin streak of magnesite)		6
Magnesite		8
Clay, greenish	1	3
Magnesite		2
Clay, greenish	1	
	4	3

The strike of the beds at this place is N. 85° W. and the dip 75° S.

North of these prospects, within a fourth of a mile, is the crest of the low rounded east-west ridge, and here are to be found occasional outcrops of the harder strata that lie on that side of the magnesite series. These ledges consist of creamy-white limestone and sandy shale layers, the shale showing chiefly as float on the surface. Some of the limestone is exceedingly cherty, the chert occurring as compact black flint nodules, in some places strewn thickly over the surface. Similar chert is to be found south of the magnesite beds, so that it doubtless both underlies and overlies the magnesite.

Another prospect on white material said to be magnesite could be seen half a mile or more east of the property examined, but this prospect was not visited.

The magnesite can be obtained in very clean white masses, as it readily separates from the inclosing clay. It is pure white, very fine grained, and compact, breaking with a china-like conchoidal fracture, such as is characteristic of most magnesite. On exposure to the air, however, the material from this deposit shows a tendency to break down that has not been noted at other deposits. A rain a short time before the date of visit had wet the magnesite on the prospect dumps and the lumps were said to have cracked and broken down like lime starting to slack. It was observed that only the more freshly dug material afforded solid specimens. Disintegration by weathering may give to the surface of these deposits a somewhat coarser and more earthy texture than the porcelain-like fracture characteristic of magnesite, but the rock has nevertheless a marked similarity to the typical magnesite. It would perhaps be surprising if a sedimentary deposit of this sort should be found to carry as low a percentage of lime as is contained in many of the other California magnesites.

All other California magnesite deposits, so far as known, occur as veins in connection with serpentinized magnesian rocks, usually referred to as serpentines. No evidence of any association with serpentines was observed at the Bissell deposits.

A suggestion as to the possible origin of these deposits may be found in considering the character of the salines commonly associated with the lake-bed deposits of the desert basins. Magnesium is commonly absent from the soluble salts of the desert-lake salines, although magnesium salts are common constituents of spring waters in Tertiary and Mesozoic rocks in other parts of the Western States. Many of the lake waters now in the Great Basin area are rich in sodium carbonate, which would of course precipitate as magnesium carbonate any soluble magnesium salt introduced. Possibly, therefore, spring or other waters bearing magnesium salts, generally the sulphate, entered a lake basin containing sodium carbonate in solution, with the result that magnesium carbonate was precipitated, forming bedded deposits. The relatively greater solubility of magnesium sulphate compared with calcium sulphate would perhaps explain the predominance of magnesia over lime in the resulting precipitate. It is also suggested that if this magnesite were thus precipitated it would probably be, in part at least, laid down as hydromagnesite, and that it would have been deposited more thickly near the source of supply and thus the beds would necessarily be lenticular.

RIVERSIDE COUNTY.

Production from the deposit of magnesite now being worked near Winchester, Riverside County, Cal., has continued since the later part of 1908 with a uniform and normal growth. This deposit has been described by Hess,[1] and only a few additional notes chiefly concerning its present status will be given here. The illustrations accompanying Hess's account represent well the character of the veins.

The Winchester deposit is owned and operated by the California Magnesite Co. and the entire product of the mine at Winchester is manufactured into cement or is sintered for furnace use at the company's plant in Los Angeles. This appears to be the only output of domestic magnesite that is utilized largely for plastic purposes. A large part of the company's product as shipped consists of finely ground plaster, which is marketed in barrels and is quoted at a much higher price than the raw or roughly calcined product from other mines.

The magnesite mined at Winchester is derived from deeply decomposed serpentine rock, which is found at the crest of one of the steep peaks that form the divide between the valley in which the town of Winchester is situated and Diamond Valley, on the south. The mine is about 2 miles in an air line from the nearest point on the railroad and is 4 miles by good road from the shipping point at

[1] Op. cit., pp. 38-39.

Winchester. The broad, flat valley north of the magnesite property is largely under cultivation and the steep little hills at its margin rise abruptly 600 to 700 feet. The open cut of the magnesite mine is about 500 feet above the level of the plain at the valley margin.

The accompanying map (fig. 54) is a topographic and geologic sketch plat of the property including the magnesite mine, reaching from the margin of the valley plain to the crest of the dividing ridge. The property all lies within the NW. ¼ sec. 31, T. 5 S., R. 1 W.

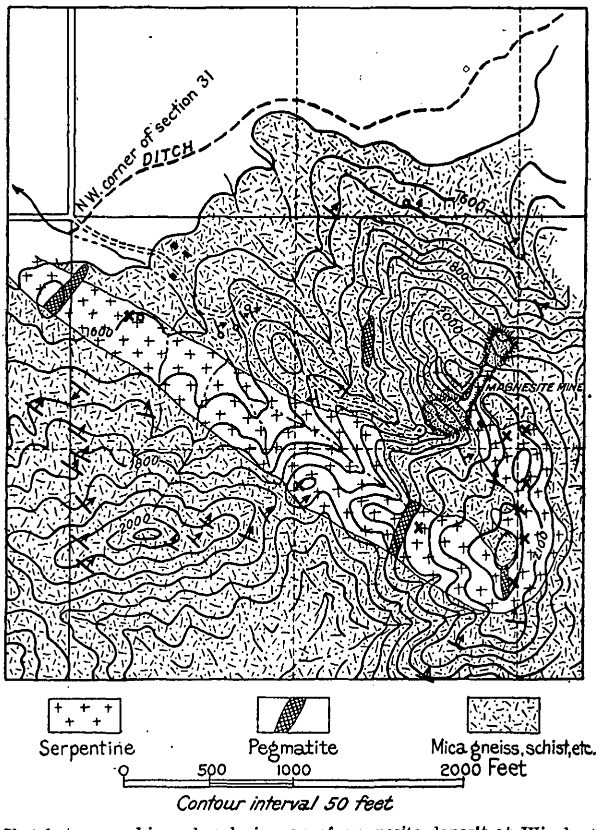

FIGURE 54.—Sketch topographic and geologic map of magnesite deposit at Winchester, Riverside County, Cal.

The area is geologically somewhat complex. It consists essentially of dark-banded micaceous gneisses and schists, in which the foliation trends in general from northwest to southeast and dips steeply to the northeast. The gneiss suggests sedimentary origin, some of the more quartzitic layers resembling conglomeratic material much distorted by shearing. Probably intrusive into the micaceous gneiss is a belt of serpentine from 200 to perhaps 400 yards wide, extending in a northwest-southeast course from a point near the northwest corner of the section. Both micaceous gneiss and serpentine are cut by pegmatite dikes, but it appears that some of the larger white pegmatitic feldspar dikes terminate within the serpentine. Crystals of black tourmaline are numerous in some of the dikes.

There are exposures of coarsely crystallized basic rock, which may be the original intrusive, now largely altered to serpentine. A very fresh specimen of this rock, when examined in thin section under the microscope, proves to be a peridotite composed essentially of olivine and enstatite. F. C. Calkins has examined a specimen of the freshest of this material from the gulch just below the mine. He reports as follows:

> The chief minerals are enstatite (pale) and olivine (dark). Other original minerals revealed by the microscope in small quantity are iron oxide, probably chromite; colorless amphibole, probably tremolite; and diallage, forming a few thin laminæ intergrown with enstatite. A good deal of talc and some carbonate and pale chlorite are present. They seem to have been formed for the most part by the alteration of enstatite, although small particles are scattered through the olivine. The olivine, however, is remarkably fresh—far more so than the enstatite. The cleavage cracks of the olivine contain opaque dust, probably magnetite, and perhaps a very little serpentine, but serpentinization has no more than barely begun.

Many pits on this property expose networks of thin veins of magnesite in serpentinous rock decomposed in place. The principal deposit of this sort is that shown in a large open cut crossing the summit of the ridge at its north end and making a prominent landmark visible for miles through the valley on the north. This cut is about 85 yards long and some 25 yards wide at its widest place and is intrenched to a depth of 60 to 75 feet in the crest of the ridge. Dumps have been thrown out at both ends, and from this cut all the magnesite shipped has been taken out. The cut shows a network of magnesite veins throughout, these being fully as numerous and of as great individual thickness at the present bottom of the pit as they were near the top, or possibly the size and thickness of the veins are even increasing with depth. Shear planes within this mass are bounded by banded alteration zones of talc, chlorite, and doubtless other secondary magnesian minerals.

A sample of the magnesite at this place collected by the author was made up of 30 separate portions collected at various parts of this cut and is believed to be representative of the material as mined. The following analysis of this sample was made by J. G. Fairchild in the laboratory of the Geological Survey, at Washington:

Analysis of average sample collected from magnesite mine at Winchester, Cal.

SiO_2	6.17
$Al_2O_3+Fe_2O_3$	.80
CaO	Trace.
MgO	43.80
CO_2	45.02
Undetermined	4.14
	100.00

The following average taken from a mill run shows the composition of the product ground for plastic use, as it is barreled for shipment. The analysis was made by E. Miall Skeats, chemist for the company.

Analysis of ground magnesite.

Insoluble	14.00
Iron and alumina	.80
Calcium oxide	.61
Magnesium oxide	84.59
	100.00

The recoverable and available magnesite veins possibly constitute one-tenth of the mass, although the actual proportion of magnesite in the finer form may be considerably higher. Thus 8 to 10 or more wheelbarrow loads of waste go over the dump for 1 load of magnesite saved. There is much fine magnesite in the dump, and it has been suggested by the owners that this might be utilized directly in the manufacture of brick. Some experiments have been made with this end in view.

The deposit at Winchester presents several features that might be considered almost unique. In the first place, the rather exceptionally favorable situation of the deposit for mining and also for shipment gives to it a distinct advantage. In many other situations it would doubtless be impracticable to mine, separate, and ship magnesite occurring in a network of thin veins traversing a massive body of serpentinous rock. As stated, the whole mass is so deeply weather-decayed that it breaks down easily and is mined by open cuts with some blasting, the ore and waste being worked over by hand labor, with pick, shovel, and wheelbarrow. However, the magnesite readily separates from the much-decomposed country rock, crumbling away as dug, leaving the fragments comparatively clean to be sorted by hand. Exception has to be made when the whole is wet by rain, as the serpentine does not crumble, and this renders necessary a suspension of operations in the open pit. The situation of the deposit at the crest of a steep slope is an important factor, as it affords a ready dump for waste and convenient sites for ore chutes and loading bins. The mining methods are therefore of the simplest type.

At least some of these peculiarly favorable features are in a measure related to surficial conditions. A protecting cap of the harder gneiss at the crest of the ridge has held in place the underlying serpentine, while on the flanks of the ridge this mass has been exposed to deep surficial decomposition. This has resulted in disintegration of the country rock bearing the magnesite veins. Prospecting at greater depth may reveal a harder mass of the magnesite-bearing rock, from which it may be more difficult to separate the magnesite. At present there are no especial indications that the deposit decreases in magnesite content as depth increases.

NEVADA DEPOSITS.

NYE COUNTY.

Reports of a deposit of supposed magnesite at a locality in the southern part of the Amargosa Desert, near Ash Meadows, Nev., have been received from several sources. A recent communication from that vicinity, transmitting a specimen of the rock, described the deposit as located half a mile northeast of the spring at the Fairbanks ranch. This is in T. 17 S., R. 6 E., 7½ miles northeast of the Nevada-California line. The ranch and spring are represented on the Furnace Creek topographic map published by the United States Geological Survey.

The specimen referred to above has been submitted to analysis in the Geological Survey laboratory at Washington, showing the following composition:

Analysis of supposed magnesite from deposit near Ash Meadows, Nev.

[W. D. Hicks, analyst.]

SiO_2	0.58
Al_2O_3	.00
Fe_2O_3	.13
CaO	55.17
MgO	.19
CO_2	42.90
Undetermined	1.03
	100.00
Loss on ignition	43.85

This rock was white and fine-grained and had the conchoidal fracture and other appearance of typical magnesite. The analysis shows the specimen to be carbonate of lime, or limestone, about 98 per cent pure with relatively very minor amounts of impurities. If the specimen received is representative, the deposit is therefore not magnesite at all.

ESMERALDA COUNTY.

Several reports of deposits of magnesite near or in the Lone Mountains, near the south end of the Big Smoky Valley, and southwest of Tonopah, somewhere near the Mount Diablo base line, Rs. 39 to 41 E., have been received. Some samples and analyses purporting to represent rock from that locality have been shown by persons interested in the deposits. These exhibit typical magnesite, apparently of good grade. Much secrecy seems to have been maintained as to the situation of the deposits, which the writer has not visited, and therefore little can be said concerning them.

CELESTITE DEPOSITS IN CALIFORNIA AND ARIZONA.

By W. C. Phalen.

INTRODUCTION.

The Geological Survey has received in the last year inquiries by foreign chemists regarding American occurrences of strontium minerals. Many of the domestic occurrences are of minor extent and most of them are of no commercial value at the present time, but as the two deposits here described may prove to be of some future importance, it has been thought worth while to publish some notes on them.

The writer takes this opportunity to acknowledge the courtesies extended by Messrs. H. H. Kerckhoff, T. L. Henderson, and Percy McCabe, president, secretary, and mine superintendent, respectively, of the Avawatz Salt & Gypsum Co., in assisting in the work and in placing at his disposal a report on the area in which this company's deposits lie, prepared by J. O. Lewis under the direction of Harry R. Johnson, which facilitated the field studies. Acknowledgments are also due to Capt. W. D. Conrad and Mr. Lambert Frye, of Gila Bend, Ariz.

SOURCES OF STRONTIUM SALTS.

The two strontium minerals of commercial importance are celestite ($SrSO_4$) and strontianite ($SrCO_3$). Strontianite is the more valuable, as by simple treatment with acids it is readily converted into the salts desired for commercial purposes. It is, however, rarer than celestite and therefore has been mined on a comparatively small scale.

Celestite, the strontium sulphate, may contain small quantities of calcium or barium—metallic elements that are isomorphous with strontium and may replace it. Celestite is highly crystalline, has a vitreous luster, inclining to pearly, and usually has a perfect prismatic cleavage. Most of it is white with a faint bluish tinge (to which it owes its name), but some has a reddish tinge. Its specific gravity varies from 3.95 to 3.97 and its hardness from 3 to 3½, being about that of calcite.

Strontianite, the carbonate of strontium, commonly occurs in crystals and crystalline masses of white to very pale green color, but in places it exhibits shades of gray, yellow, and yellowish brown. It is a brittle mineral, with nearly perfect prismatic cleavage and a hardness of 3.5 to 4. Its high specific gravity, 3.68 to 3.71, serves as one of the means of identifying it. As in celestite, the strontium may be replaced by more or less barium or calcium.

Celestite and strontianite are readily determined before the blowpipe. Both of them give a crimson flame due to the element strontium and after intense ignition give an alkaline reaction when placed on moistened tumeric paper. Celestite fuses readily and when heated with sodium carbonate and a reducing agent like charcoal produces a dark stain of silver sulphide when placed on a piece of moistened silver, thus indicating the presence of the sulphate radicle in the compound. Strontianite effervesces when treated with dilute hydrochloric acid, thus indicating the presence of carbonic acid.

USES OF STRONTIUM.

The metal strontium is not commercially used so far as the writer is aware, but its salts are variously employed. Of these the hydrate and nitrate are of greatest importance. Different textbooks and dictionaries on industrial chemistry give different methods whereby the hydrate is made from the sulphate. In general, however, the principles involved are the reduction of the sulphate to the sulphide either by charcoal or coal, the extraction of the sulphide with water, and the subsequent precipitation of the hydrate by a metallic oxide or hydrate. A very simple process for obtaining the hydrate is the calcination of the carbonate, strontianite, where it is available. The temperature required is much higher than that of ordinary lime burning.

Strontium hydrate is used principally in the recovery of sugar from beet molasses. The process is still employed in Germany and by the Raffinerie Parisienne, but the cost of the hydrate is too great for its use to become general. Strontium sucrate (saccharate) is much more easily formed than calcium sucrate, and for this reason the celebrated German chemist, Carl Scheibler, of Berlin, has urged the use of strontium hydrate in sugar factories, especially as Germany has extensive deposits of strontium minerals from which it has been possible heretofore to obtain the hydrate cheaply. The beet molasses is mixed in suitable proportions with the hydrate and the sucrate is formed. The mother liquors are separated by filter presses. The cakes of strontium sucrate are washed, then mixed with water, and carbonated. The strontium carbonate thus formed is burned to the caustic condition and used over again.

Strontium nitrate is made by dissolving the carbonate in nitric acid, if the native mineral can be procured sufficiently free from other bases that would consume the acid. The carbonate used is sometimes made from the sulphate by fusing it with soda ash and leaching out the sodium sulphate formed by the double decomposition: $SrSO_4 + Na_2CO_3 = SrCO_3 + Na_2SO_4$. The chief use of strontium nitrate is in pyrotechny, where it imparts a red color to the flame. The chlorate and carbonate are also used for this purpose but to a less extent.

Strontium in the form of the iodide, bromide, acetate, lactate, arsenate, phosphate, and other salts is used as medicine and in the chemical laboratory.

VALUE OF STRONTIUM MINERALS.

Celestite can hardly be assigned a value in the United States, because heretofore it has not been found in sufficient quantities and in positions accessible enough to make its exploitation profitable, in view of the scant demand for it. At the present time, therefore, it may be considered to have only a potential value. When attention is drawn to important deposits very likely uses will be developed for it. The uses already discovered, as indicated above, and the fact that it is manufactured in Europe into chemicals that are imported into the United States suggest that the time may come when the more extensive deposits in this country may be worked.

DEPOSITS OF STRONTIUM MINERALS.

Mode of occurrence.—The metal strontium is intermediate in the periodic system between calcium and barium. It is found in small amount in the igneous rocks, an average of 611 analyses showing its presence to the extent of 0.04 per cent in the form of its oxide (SrO), and to the extent of 0.033 per cent in elementary form. It can be detected in sea water by ordinary methods. It is also found in the ashes of sea weeds and in boiler scale.

Strontium and calcium are chemically so closely related that their common association in rocks is to be expected. In any natural sequence of chemically deposited sediments the solubility of strontium sulphate places it above a calcareous deposit ($CaCO_3$) and below calcium sulphate (gypsum). It follows, therefore, that celestite may be dissolved away from lime and redeposited to form secondary masses. It also follows that its common association with gypsum and calcareous sediments in general is to be expected.

Celestite is usually associated with limestone or sandstone. It may also occur in beds of gypsum, salt, or clay. Locally it is associated with metalliferous ores, as with galena and sphalerite. In places it fills the cavities in fossils and in certain volcanic regions it is associated with sulphur.

New York.—In the United States celestite is much commoner than strontianite. In a few places the two minerals are known to occur together. In the vicinity of Schoharie, Schoharie County, N. Y., the minerals have been found in a rather impure limestone. They occur in pockets and thin seams and have been found in greatest quantity on the east side of Schoharie River, near quarries in limestone of the Helderberg group. The combination of strontium minerals is known to extend for about a mile west of the river, but their extent east of the river is unknown, as no openings have been made in the limestone in this direction.

Strontianite occurs in rocks of the Clinton formation near Clinton, Oneida County, N. Y., associated with celestite in geodes. The carbonate forms the outer part of the geode, inclosing the sulphate.[1] The nodules and geodes are found in limestone and sandstone beds and also in the oolitic iron ore beds of the vicinity. The best examples of the occurrences were found at the old quarries near Lairdsville, 2 miles west of Hamilton College.[2]

Celestite and strontianite have also been found near Theresa and on the shore of Chaumont Bay, in Jefferson County, N. Y.

In the town of Adams, about 2 miles from the village of Adams Center, in Jefferson County, a vein of celestite is known to occur in the Trenton limestone. An occurrence has also been reported near Lockport, Niagara County. E. H. Kraus[3] has reported celestite as disseminated through dolomitic limestone near Syracuse. Other places in New York where celestite is said to occur are at the Rossie lead mine and Stark, in St. Lawrence County, and at Depauville, in Jefferson County.

Ohio.—One of the most noted localities in the United States where strontium minerals have been found is Put-in-Bay, South Bass Island, Ottawa County, Ohio. Here celestite was found in 1897 during the sinking of a well, the walls of which caved in, revealing a cavern in limestone. The floor, ceiling, and walls of the cave were found to be composed of celestite, and the owner reported that the mineral was found to a depth of 22 feet below the floor. Traces of strontia were found in the vicinity. Of the 150 tons of celestite removed, 40 tons was exported to Germany.

Texas.[4]—In 1904 a deposit of celestite was developed 5 miles north and a little west of Austin, Tex., in the Mount Bonnell and Mount Barker district. The celestite is associated with strontianite, Epsom salts, and other minerals and occurs in a flat-lying arenaceous and argillaceous magnesian limestone bed in the Glen Rose limestone (Lower Cretaceous). The limestones are soft, are of a rich cream or yellow

[1] Am. Jour. Sci., 2d ser., vol. 13, 1852, p. 264.
[2] Idem, 3d ser., vol. 33, 1887, p. 286.
[3] Idem, 4th ser., vol. 18, 1904, p. 30.
[4] First Rept. Geol. Survey Texas, 1889, p. 125. Third Rept. Geol. Survey Texas, 1891, p. 229. Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, pp. 144–147. Hess, F. L., Eng. and Min. Jour., vol. 88, July 17, 1909, p. 117.

color, and alternate with softer marls of similar composition, containing pockets or nodules composed of calcite, aragonite, strontianite, and celestite. From measurements made on photographs Hess estimates that there is not more than 5 per cent of celestite in the richest exposures observed.

The celestite has been found in cleavable masses of irregular shapes, varying in weight from half a pound to 100 pounds. In developing the deposits it has been necessary to blast the rock, although it is rather soft. The deeper the work has extended into the hill (about 50 feet below the summit of Mount Bonnell) the purer and more abundant was the celestite obtained. Its color varied from white to pale bluish gray.

Samples analyzed by Ledoux & Co., of New York City, after drying at 212° F., showed 97.64 per cent of $SrSO_4$, and tests made in the laboratory of the University of Texas showed the samples to be 98 per cent pure. In 1904 a carload of the ore was mined and shipped to Germany, but money was lost by the transaction.

West Virginia.—An occurrence of celestite has been noted near Cedar Cliff, Mineral County, W. Va., and an account of the crystals found there has been given by G. H. Williams.[1] The rock in which the celestite crystals occur is a thickly bedded, nearly horizontal argillaceous limestone, similar to that used in the neighboring cities in Maryland in the manufacture of cement. The celestite occurs in crystalline form in flattened lenticular cavities or pockets from a foot to a yard in diameter and from 3 to 7 inches in height. The cavities apparently represent foreign concretions. In the adjacent limestone strontium sulphate was found so abundantly as to indicate that the rock was strongly impregnated.

Other occurrences in the United States.—Celestite is known to occur at Drummond, Chippewa County, Mich. In Monroe County of the same State, according to E. H. Kraus and W. F. Hunt,[2] it is found disseminated through dolomite, and at the point especially studied the upper layer of the rock contained over 14 per cent of celestite. Below this layer there is a porous stratum with cavities containing celestite and free sulphur. The latter is found in considerable quantities and was probably formed by reduction of the sulphate.

Celestite has also been found near Frankstown, Blair County, Pa.; in Brown County, northeastern Kansas; in Larimer County, Colo.; in cavities in limestone near Nashville, Tenn.; and associated in fine clear crystals with the colemanite of Death Valley, San Bernardino County, Cal.

Strontianite occurs with celestite in New York, as already noted, and is also found in Mifflin County, Pa.

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[1] Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 183-188. [2] Idem, 4th ser., vol. 21, 1906, p. 237.

Foreign occurrences.—Nearly all the strontium salts used in the United States are imported from Germany. The German manufacturers obtain their raw material in part near Hamm and Munster, Westphalia, where considerable quantities of strontianite are found, and from Thuringia, both States in the western part of the German Empire; also from Sicily, where celestite occurs in abundance. The presence of extensive deposits of strontium minerals at places where they may be mined cheaply is one of the reasons why the salts derived from them are used so extensively in Germany. Other reasons are outlined in the section on uses. For information concerning other foreign occurrences of strontium minerals, of which there are many, the reader is referred to the works of Dana,[1] Clarke,[2] and others.

CELESTITE IN CALIFORNIA.

Location.—Celestite, together with salt, gypsum, and other important economic minerals, occurs along the northeast margin of the Avawatz Mountains, in San Bernardino County, Cal. The minerals are located on land of the Avawatz Salt & Gypsum Co., which has 52 claims containing about 5,200 acres. These claims are located near and tied by survey to Government monuments at the south eighth corner west, sec. 15, original quarter corner between secs. 22 and 23 and original quarter corner between secs. 25 and 26, T. 18 N., R. 5 E. San Bernardino meridian. They lie in a belt 9 miles long by 1½ miles wide in spur ridges along the northeast margin of the Avawatz Mountains, near the south end of Death Valley. The nearest railroad is the Tonopah & Tidewater, about 10 miles east of the southeast end of the claims. Figure 55 gives the general location of the claims with reference to well-known points in southern California.

Topography.—The spur ridges on which the properties are located are trenched by the drainage channels of the mountains and indented by alluvial fans composed of material similar to that found in the valleys north of the deposits. This material is the wash brought down from the mountains. The country slopes off gradually from the edge of the hills, where the gradient is steep, to the center of the valley, where it is very gentle and renders railway or highway construction comparatively easy, so far as the topography is concerned. In general it may be said that the details of the topography are rough. (See fig. 56.)

Geology.—There are three general divisions of the rocks which are of economic importance. These are (1) a basement complex of stratified rocks which have been metamorphosed and intruded by igneous rocks; (2) lake beds containing salt, gypsum, and celestite; and (3) gravels concealing the older beds.

[1] Dana, J. D., System of mineralogy, 6th ed., 1909, p. 905.
[2] Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, pp. 552–553.

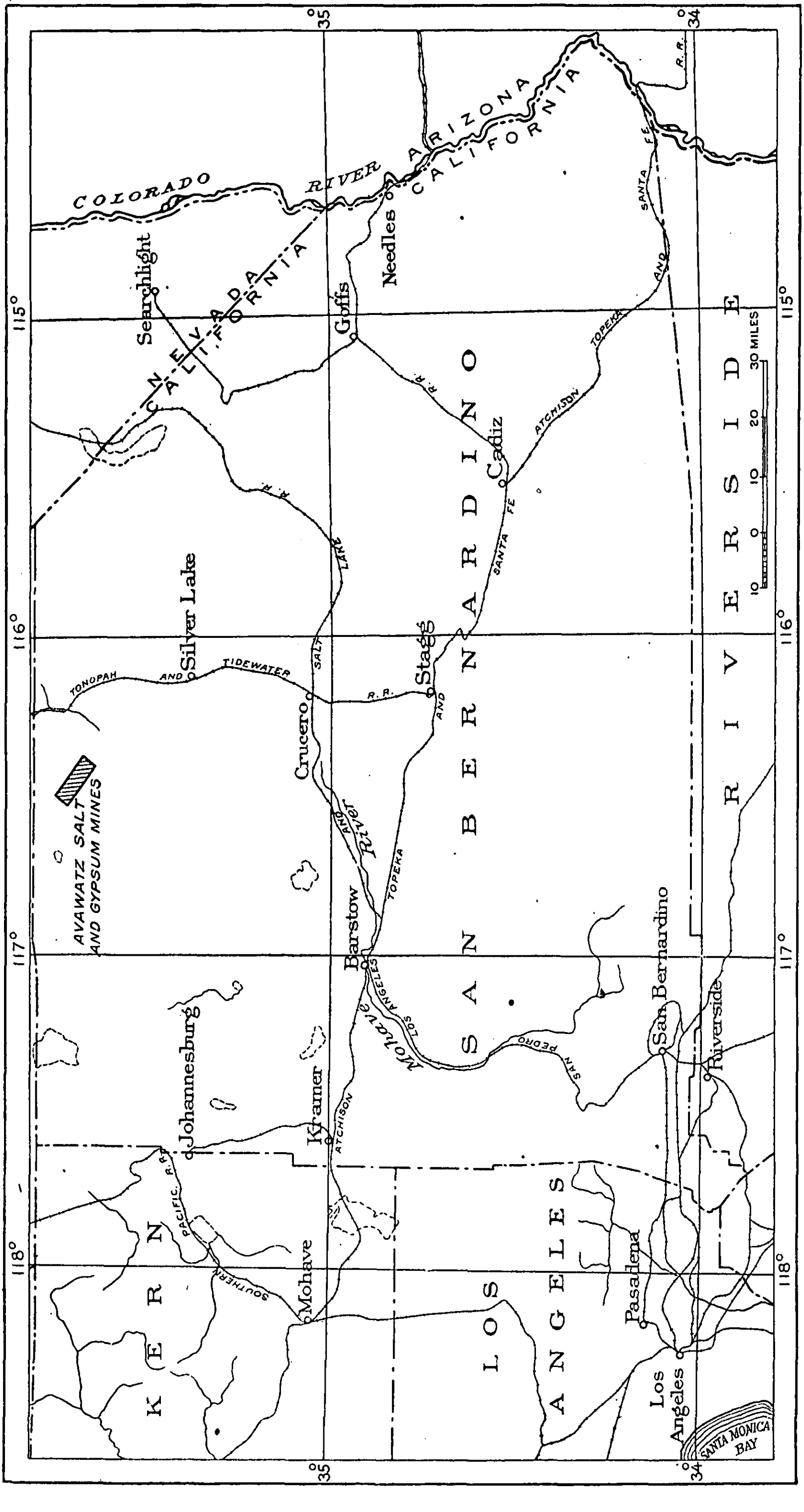


FIGURE 55.—Key map showing location of claims of Avawatz Salt & Gypsum Co., San Bernardino County, Cal.

The lake beds are separable into five main divisions—the basal series of lake beds, the celestite beds, the gypsum series, the salt series, and the upper series of lake beds.

The basal or lower lake beds are made up of conglomerates, sandstones, shales, and soft clays, the whole having in general bright colors. They may thin or be entirely absent in places. Detailed work may develop the fact that there are two distinct series in these lower lake beds, possibly separated by an uncomformity. This suggestion is based on differences in degree of consolidation, in coloring, etc. These lower lake beds contain in some places gypsum and beds of

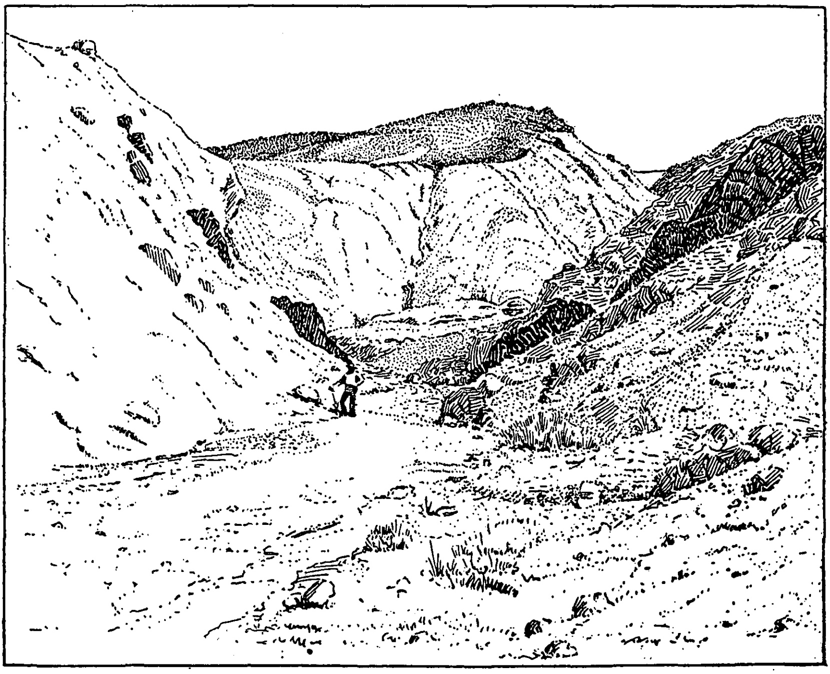


FIGURE 56.—Outcrop of bedded celestite deposit (dark ledges) in Avawatz Mountains, San Bernardino County, Cal. Sketched from photograph.

celestite at various horizons. The thickness varies from place to place, being abnormal where there is much repetition by faulting.

Above the lower lake beds and below the gypsum occur the celestite beds, which were observed in general from the middle of the claims to their west end. The principal outcrops observed were near and west of the Jumbo salt outcrop. The celestite is exposed in the form of resistant "hogbacks," in some places flanking the ridges and in others cutting them and continuing across the valleys between them.

The thickness of the celestite zone may be locally as much as 75 or 80 feet, but the exact thickness is difficult to ascertain in all places owing to the presence of wash and talus. East of Cave Springs Wash the outcropping reef or band of celestite was paced and found to be about 75 feet thick. It must not be understood that the entire thickness of the outcropping reef is pure celestite. It is more than probable that the pure mineral will be found in some places in thin bands and streaks and in others more or less intimately mixed with other substances, for example, gypsum, quartz in the form of sand or chalcedony, clay, and the oxides of manganese, iron, etc.

Careful prospecting and sampling will be necessary before the deposits are worked to determine accurately where the purest material occurs in the largest amount and in the best position for exploitation. It is to be expected that some of the material in the celestite zone will prove to be of low grade.

There is no sharp dividing line between the lower series of lake beds and the overlying celestite and gypsum beds, the different series merging into one another gradually. There is also no sharp division between the gypsum and the overlying salt beds, or, in the absence of the salt series, between the gypsum and the overlying shales and clays. In a series of chemically deposited sediments this is to be expected. The division made above, however, is convenient for descriptive purposes.

In the stratigraphic sequence the salt overlies the gypsum beds. As a rule it is massive and does not show crystalline structure. Its color is usually reddish or brown, the discoloration being due to small amounts of iron oxide or colored clay. In general the line of separation between the salt and the underlying gypsum can be readily made out where exposures are good. The exposures of the gypsum are a as a rule light colored; those of the salt are dull or reddish brown from the residual clay left from the solution of the salt. Toward the base of the salt series occur saline clays and sands with some dolomite or gypsum, followed in upward sequence by the main salt beds, which are in turn overlain by saline clays and sands that merge with the overlying lake beds. The arid climate accounts for the appearance in places of massive salt outcrops practically at the surface. In places the salt is not present where the stratigraphic sequence indicates that it would be natural to expect it. Its absence may be accounted for on several hypotheses, such as nondeposition, solution, or faulting.

The upper lake beds overlie the salt and consist chiefly of gravels, clays, and sands, with local thin saline beds and small quantities of gypsum. It is possible that in places these beds may be or include the stratigraphic equivalent of the salt beds.

In a general way the strike of the beds follows the north edge of the Avawatz Mountains, curving to the northwest, as indicated in figure 55. Earth movements have been intense in the region, and the rocks show faulting and folding on both a large and a small scale. The general trend of the folds is to the northwest. There is a finely developed fold in the lake beds near the mouth of Denning Spring Wash, not far from the west end of the deposits. The faulting and folding have resulted in steep dips and many of the beds stand nearly on edge. Figure 56, sketched from a photograph, illustrates this feature and gives a better idea of the "hogback" nature of the outcrop of the resistant celestite than could be obtained from a text description.

Physical character.—The typically exposed reefs of celestite are dark brown in color and are conspicuous beside the light-colored gypsum. This dark-brown color may be due to the presence of manganese or iron oxides, or both, but in general it is more suggestive of the former than of the latter. Not all the celestite is dark brown; a great deal of it is of light color, and the deep color is more characteristic of the exposed than of the freshly fractured mineral. In texture it varies from compact to coarsely crystalline. The crystalline nature of most of the mineral collected is apparent in hand specimens. Its high specific gravity is a help in identifying it in the absence of other heavy nonmetallic minerals, of which barite is an example.

Chemical character.—In its pure form celestite or strontium sulphate contains 56.4 per cent of strontium oxide (SrO) and 43.6 per cent of sulphur trioxide, or sulphuric anhydride (SO_3). These figures will help in indicating the purity of the samples whose analyses are given below and on page 533.

Analyses of celestite from Avawatz Mountains, Cal.

	1	2	3
Strontia (SrO)	50.99	38.41	47.92
Equivalent in terms of strontium sulphate ($SrSO_4$), or celestite	90.42	68.11	84.98

1. R. A. Perez, Los Angeles, Cal., analyst. Analysis furnished by Avawatz Salt & Gypsum Co. The entire analysis as reported by Perez is as follows:

Strontium oxide (SrO)	50.99
Calcium oxide (CaO)	.75
Barium oxide (BaO)	Trace.
Sulphur trioxide (SO_3)	42.38
Carbon dioxide (CO_2)	.92
	95.04

Gold, trace; silver, trace. Siliceous material, moisture, water of crystallization, etc., not determined.

2, 3. Samples collected near the west end of the property by W. C. Phalen. Analyses made in the laboratory of the United States Geological Survey by W. C. Wheeler.

Qualitative tests made on samples 2 and 3 showed the presence of ferric oxide and alumina. Manganese, lime, and barium were found in all the samples, as was also carbon dioxide. The amount of sulphur trioxide in each sample selected for quantitative analysis was larger than was required by the strontium present, which is believed to be wholly in the form of the sulphate. The excess of sulphur trioxide is probably present chiefly as sulphate of calcium, probably in the form of gypsum. The small amount of barium present is also probably in the form of the sulphate. The carbon dioxide is mostly present in carbonate of calcium.

The specimens were selected with no special attempt to procure the richest material, but simply with the idea of taking representative material of good grade. The content in strontium sulphate in the material thus selected is noteworthy.

CELESTITE IN ARIZONA.

Location.—Celestite occurs 15 miles south of Gila Bend, Maricopa County, Ariz., on unsurveyed land, so far as can be told from the State map issued by the General Land Office. The claims which cover the occurrence are known as the Montezuma claims Nos. 1, 2, 3, 4, and 5, and are under location by W. D. Conrad and Lambert

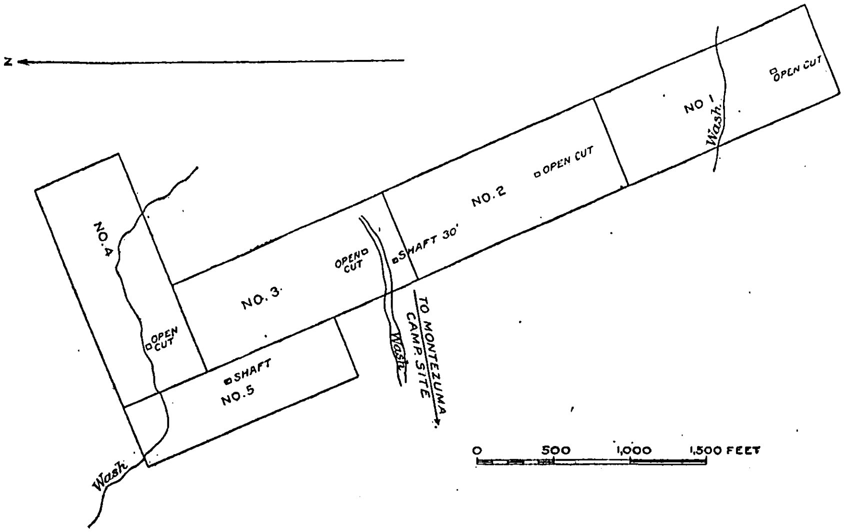


FIGURE 57.—Sketch map of Montezuma mining claims, 15 miles south of Gila Bend, Ariz.

Frye, of Gila Bend. The southeast end of the claims is a short distance S. 80° E. from Montezuma, a well-known camp site for travelers going into the country south of Gila River. (See fig. 57.)

General relations.—The deposits are located well down on the side of a ridge that forms part of a somewhat isolated group of hills, such as are characteristic of this general region. Toward the west there is a broad expanse of level land, a mesa or old lake valley, slightly dissected by "dry washes," through which water runs at certain seasons of the year or after severe rains.

The main mass of the hills in which the sedimentary deposits occur and the surrounding hills to the northeast and east are made up of basalt, of the compact, vesicular, and porphyritic varieties. A basalt dike about 20 feet in thickness cuts across the sedimentary series in an east-west direction at the south end of the claims and forks east of the deposits. Toward the northwest end the sandstone underlying the celestite bed proper is underlain by porphyritic basalt striking N. 40° W., in substantially the same direction as the sedimentary beds with which it is associated.

Occurrence.—The celestite occurs in a sedimentary series associated with gypsum, sandstones, and conglomerates containing pebbles of coarse-grained granite. The series is involved with igneous flows and intrusions. At the south end of the deposits the strike is N. 5°–20° E. and the dips are high, ranging from 45° to 70° E. Toward the north the beds swerve to the northwestward slightly, and the strike becomes N. 10°–28° W., with lower dips ranging from 15° to 35° E. The deposit is easily traced at the northwest end of the claims and may be observed extending a short distance beyond the base of the hills on the mesa proper, where it disappears beneath sands and gravels. Between the northwest end and the southeast end the deposit of celestite is hidden in places by the excessive amount of wash and talus resulting from the disintegration of the basalt in the ridge above. The length of the deposit observed is approximately 1 mile.

The celestite occurs in the form of a bed or beds overlain and underlain in some places by sandstone beds and in others by igneous flows. In the northwestern part of the deposit, where the relations and thicknesses can be best determined, the bed with which the celestite is directly associated is 40 to 50 feet thick. Of this thickness the upper 8 to 10 feet looked most promising as a source of the mineral, as judged from natural outcrops and small prospects, the remainder of the celestite zone appearing rather sandy. Careful prospecting will be necessary to determine the thickness and extent of the purer layers of the mineral, which will without doubt be found in thin beds. In places in the northwestern part of the deposit the celestite is intermixed with gypsum, as well as sandstone. Gypsum was also noted in the southeastern part of the deposit. Toward the northwest the celestite appears to occur in two main layers.

The mineral presents a variety of appearances. The high density, of course, characterizes the purest material and enables it to be readily identified in the absence of similar minerals like barite. In general it is rather light colored, both on the outcrop and when freshly fractured. A pink phase in the northwestern part of the deposit was observed, the color probably being due to iron oxide. Some of the material observed is very dark, both where exposed naturally or where freshly fractured. The dark color is possibly due to the oxides of manganese. Sandy and clayey impurities are present. The macroscopic structure would ordinarily be described as massive and crystalline. The material is nearly all massive, but on the freshly fractured surfaces the presence of small crystals is readily made out.

Composition.—The following analyses show the chemical character of the celestite:

Analyses of celestite from deposit south of Gila Bend, Ariz.

	1	2	3	4	5	6	7	8
Strontia (SrO)	....	....	....	....	....	....	49.36	48.99
Equivalent in terms of strontium sulphate ($SrSO_4$), or celestite	91.5	88.5	67.0	78.08	74.80	80.40	87.52	86.88

1. From southwestern part of claim No. 3. Rex W. Dunlap & Co., Phoenix, Ariz., analysts. Analysis furnished by W. D. Conrad.
2. From open cut on claim No. 2. Results are based on 100-pound sample sent to the California Drug & Chemical Co., Los Angeles, Cal. Analysis furnished by W. D. Conrad.
3. From south end of claim No. 1. D. W. Rickhart, El Paso, Tex., analyst. Analysis furnished by W. D. Conrad.
4, 5, and 6. From claim No. 2, near open cut. Analyst not known. Analysis furnished by W. D. Conrad.
7. From point near northwestern part of claims, upper part of bed. Collected by W. C. Phalen. Analysis made in laboratory of United States Geological Survey, by W. C. Wheeler.
8. Pink phase of celestite near northwest end of claims. Collected by W. C. Phalen. Analysis made in laboratory of United States Geological Survey, by W. C. Wheeler.

Qualitative tests of samples 7 and 8 showed the presence of ferric oxide and alumina, together with manganese, calcium, and barium. Carbon dioxide was present in sample 7 but absent in sample 8. The sulphur trioxide in these two samples was found to be in excess of that required by the amount of strontium present, which, it is highly probable, is entirely in the form of the sulphate, celestite. The excess of the sulphur trioxide is probably partly in the form of sulphate of calcium, or gypsum, which occurs on the property, and also partly combined with the small amount of barium present. Calcium carbonate is undoubtedly present in sample 7 but absent in sample 8.

As with the California samples, the material taken from the deposit in Arizona was selected with a view to procuring representative material of good grade. The results given in analyses 7 and 8 are therefore worthy of consideration.

NEW AREAS OF DIAMOND-BEARING PERIDOTITE IN ARKANSAS.

By Hugh D. Miser.

INTRODUCTION.

Four areas of peridotite near Murfreesboro, Pike County, Ark., were known at the time of the writer's visit to this region, November 27 to December 8, 1912. One of these, that near the mouth of Prairie Creek, has been known to geologists since 1842. The rock, however, was not known to be peridotite until 1889, when Branner and Brackett[1] published a paper in which they described the nature of the rock and its geologic relations. The first diamonds were found August 1, 1906, in the area near the mouth of Prairie Creek, and, according to D. B. Sterrett,[2] approximately 1,375 diamonds, aggregating about 550 carats, are reported to have been found in this area up to 1913. Since the first discovery of diamonds several writers have contributed to the literature on the Arkansas diamonds and the geology of the peridotite in this region, as indicated in the following list:

Kunz, G. F., and Washington, H. S., Notes on the forms of Arkansas diamonds: Am. Jour. Sci., 4th ser., vol. 24, 1907, pp. 275–276.

—— —— Diamonds in Arkansas: Bull. Am. Inst. Min. Eng. No. 20, 1908, pp. 187–194.

Fuller, J. T., Diamond mine in Pike County, Ark.: Eng. and Min. Jour., vol. 87, 1909, pp. 152–155, 616–617.

Branner, J. C., Some facts and corrections regarding the diamond region of Arkansas: Eng. and Min. Jour., vol. 87, 1909, pp. 371–372.

Schneider, P. F., A preliminary report on the Arkansas diamond field: Bur. Mines, Manuf., and Agr., Little Rock, 1907, 16 pp.

—— A unique collection of peridotite: Science, vol. 28, 1908, pp. 92–93.

Sterrett, D. B., Diamonds in Arkansas: Mineral Resources U. S. for 1909, U. S. Geol. Survey, 1910, pp. 757–759.

Purdue, A. H., A new discovery of peridotite in Arkansas: Econ. Geology, vol. 3, 1908, pp. 525–528.

Glenn, L. C., Arkansas diamond-bearing peridotite area [abstract]: Bull. Geol. Soc. America, vol. 23, 1912, p. 726.

For the reason that the diamonds are found in the peridotite, search for further areas of this rock has been made. As a result three others have been found, the known extent of each of which is

[1] Branner, J. C., and Brackett, R. N., The peridotite of Pike County, Ark.: Am. Jour. Sci., 3d ser. vol. 38, 1889, pp. 50–59; Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2, pp. 377–391.

[2] Personal communication.

much smaller than that of the area first discovered. They lie, as is shown in figure 58, within an area of 1 square mile, about 2 miles northeast of the earlier-known occurrence and 3 miles from Murfreesboro. One of them, namely, that in the NE. ¼ SW. ¼ sec. 14, T. 8 S., R. 25 W., was described by Purdue shortly after its discovery but has been much developed since and is therefore discussed in this report, together with the two areas near by that have not previously been described.

TOPOGRAPHY.

Much of the region in which the areas here described are located is made up of numerous even-crested hills, the height of which does not exceed 250 feet above the larger streams, or 600 feet above sea level. Their slopes are steep and are forested in most places by a second growth of small timber. Extending for a few miles to the north of these hills is an area of lower hills. Little Missouri River, flowing southward, has cut a valley 5 miles or less in width near Murfreesboro. From this stream westward to the vicinity of Center Point there is a plateau-like area, reaching a little more than 700 feet above sea level.

GEOLOGY.

SEDIMENTARY ROCKS.

The rocks of this portion of the State are all of sedimentary origin, with the exception of the four known areas of peridotite near Murfreesboro, and are of Ordovician, Carboniferous, Cretaceous, and Quaternary age. The stream gravels and silts belong to the Quaternary.

The Ordovician and Carboniferous rocks aggregate 24,000 feet in thickness in the Ouachita Mountains north of Murfreesboro and consist of shales, sandstones, novaculites, and cherts. They have been subjected to intense folding, so that the beds stand at high angles. South of the mountains the peneplained surface of the Carboniferous rocks dips to the south, and a few miles north of the area here described the rocks of this period disappear beneath beds belonging to the Cretaceous.

In the region under discussion the Cretaceous is represented by the Trinity formation (Lower Cretaceous) and the Bingen sand (Upper Cretaceous). Their distribution in T. 8 S., R. 25 W., is shown in figure 58.

The Trinity formation has a low dip to the south and outcrops in an east-west belt a few miles wide. From a locality 2 miles north of Center Point, where the formation is more than 600 feet thick, it thins toward the east and in the vicinity of Murfreesboro is much thinner. It consists of intercalated beds of marly clay, sand, gravel, and limestone. The principal bed of gravel is at the base. The limestone is in two beds, one near the top of the formation and the other near its base. The Trinity is overlain by the Bingen sand, from which it is separated by a pronounced unconformity, as is shown by the planing off of the beds of the Trinity toward the east.

The Bingen sand caps the higher hills southeast of Murfreesboro and the plateau-like area west of this town. It has a low southerly dip that brings it down to the level of the streams in this direction, and still farther south it passes beneath younger rocks. The formation consists of intercalated beds of gravel, sand, and clay. The gravel occurs in several beds throughout the formation, but the

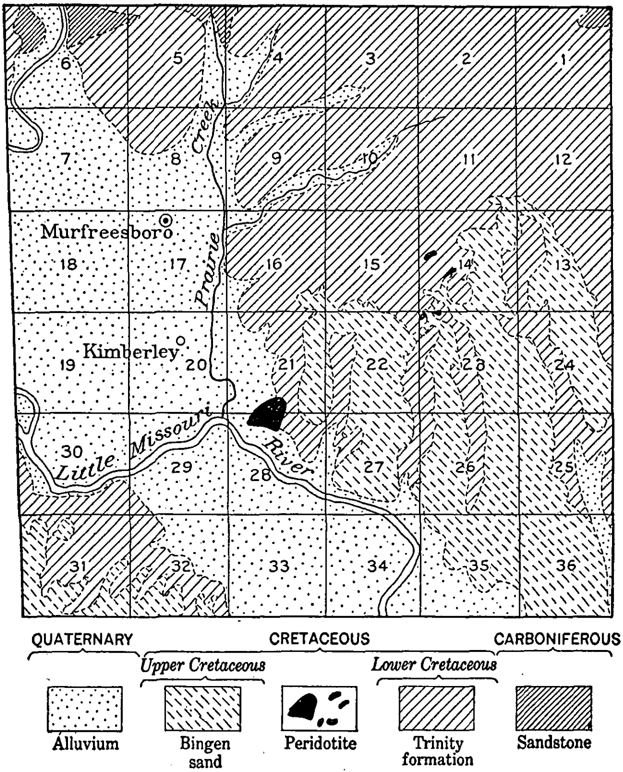


FIGURE 58.—Map of T. 8 S., R. 25 W., Arkansas, showing distribution of known areas of peridotite.

thicker beds are at and near its base. The sand is gray and is interbedded with numerous layers of kaolins and other light-colored clays. In the vicinity of Murfreesboro the upper part of the formation has been removed by erosion during the present erosion cycle and only the basal part is present.

PERIDOTITE.

GENERAL FEATURES.

Two of the peridotite areas herein described are in sec. 14 and the third in the northwest corner of sec. 23, T. 8 S., R. 25 W. (See fig. 58.)

Their geology is shown in part on Plate XI, the mapping of the rocks having been attempted only in places where they were exposed at the time of the examination. The peridotite has at almost all places disintegrated to a soft earth which produces topography not different in any way from that of the clays of the Trinity formation. As a result, surface clay, sand, and gravel generally obscure the sedimentary clay and the decomposed peridotite to such an extent that pits and ditches 2 feet and more in depth are necessary to reach material in place.

DETAILS.

PROPERTY OF KIMBERLITE DIAMOND MINING & WASHING CO.

The peridotite in the SW. ¼ NW. ¼ sec. 14, T. 8 S., R. 25 W., is on the property of the Kimberlite Diamond Mining & Washing Co. It is exposed in pits and trenches from a few feet to 15 feet in depth. It is reported in drill hole No. 7, at a depth not known to the writer, and in a well (drill hole No. 8) at a depth of 90 feet from the surface. The dike that is exposed in the trench farthest east on this property (fig. 59) is probably an eastward continuation of the known peridotite. Black soil, locally called "black ground," derived from peridotite and overlying it in many other places in this region, is not present here, but surface clay from the Trinity formation covers the disintegrated rock to a depth ranging from a few inches to a few feet. The apparent form of the intrusion, to judge from present exposures, is that of a crescent-shaped dike striking northeast and southwest, with a length of at least 700 feet and a width of possibly 100 feet at the surface, but further prospecting to the east and southeast may prove extensions of the peridotite in these directions. The contact of the peridotite with the Trinity formation was exposed at the time of the writer's visit in six different places, in all of which it is distinct, and its plane dips at a high angle from the horizontal.

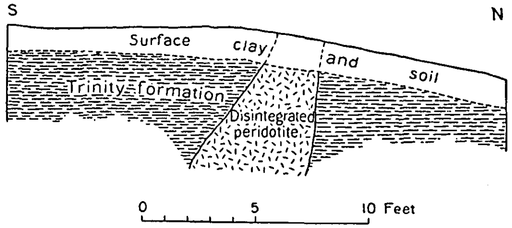


FIGURE 59.—Section of dike cutting clay of Trinity formation in sec. 14, T. 8 S., R. 25 W. Arkansas. This dike is the exposure farthest east on the property of the Kimberlite Diamond Mining & Washing Co.

The exposures indicate that the sedimentary clay for a few feet away from the contact was metamorphosed into a vitrified clay at the time of the intrusion of the peridotite. Semivitrified clay was observed in the NE. ¼ SW. ¼ sec. 14, but at the locality here described it has weathered to a clay that is now only a little harder and of lighter color than the clay away from the contact.

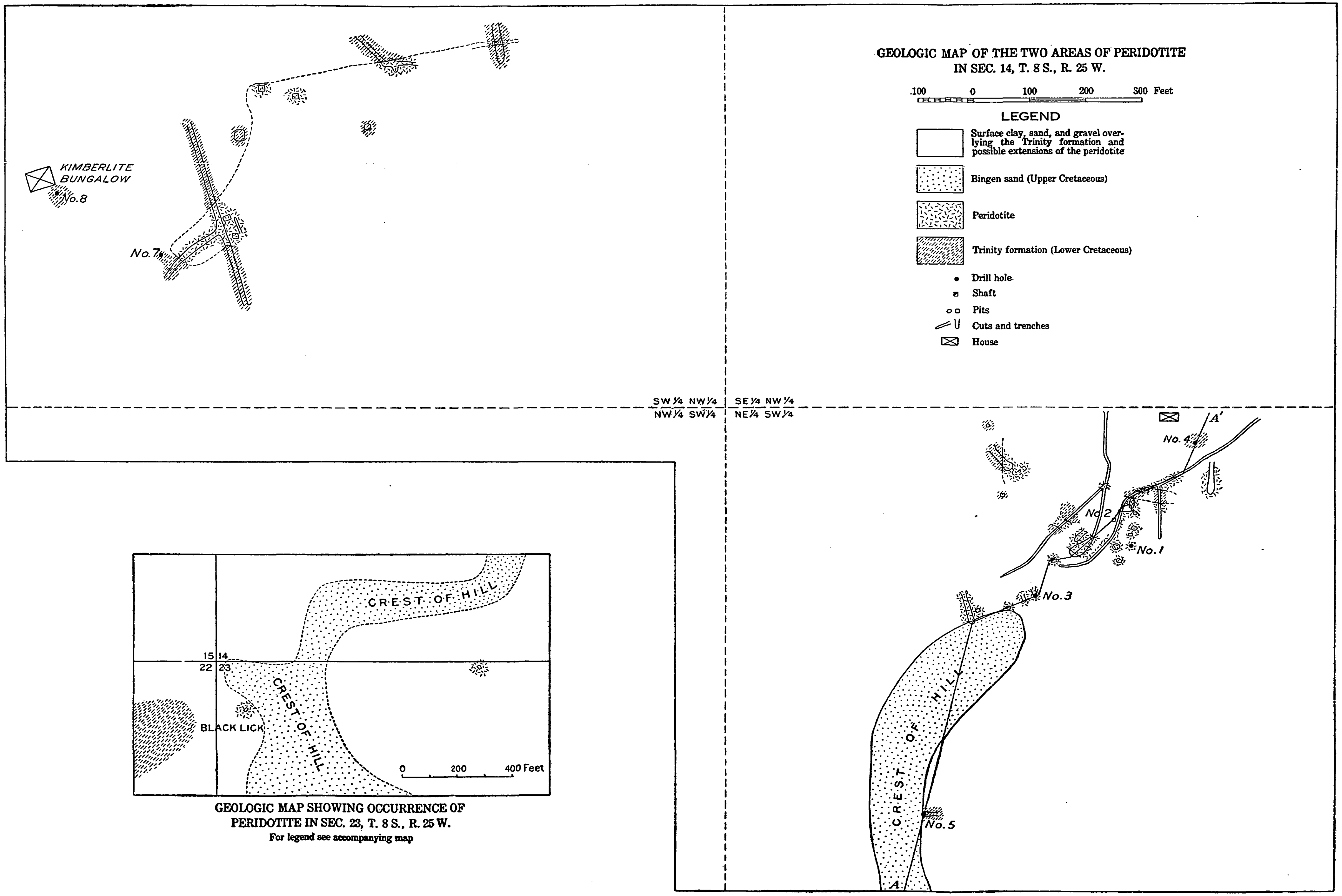
On this property unaltered peridotite is exposed only in the northeast-southwest trench at the west boundary of this rock, where it occurs as two small patches a few feet across. It was encountered in the well (drill hole No. 8) near the Kimberlite Bungalow. Elsewhere it has disintegrated to a soft green and yellow earth, the depth of which is not known.

The unaltered peridotite on this property is dense, tough, porphyritic, and dark greenish black. The hand specimen shows numerous phenocrysts of more or less altered olivine in a dense brownish-black groundmass. Many inclusions of black shale derived from the Paleozoic shales beneath are present. These inclusions at different places in the disintegrated rock reach 2 inches in diameter. They were baked by heat from the peridotite at the time of its intrusion, and though they are much weathered near the surface, they are still harder than ordinary black shales.

Microscopic study shows that the rock is similar in both texture and mineral composition to that of the area first discovered. The thin sections show numerous olivine phenocrysts in a groundmass consisting of augite, biotite, perofskite, and magnetite embedded in a colorless glass base which often polarizes. The olivine crystals are in part bounded by their faces; they make up 20 to 25 per cent of the rock and are more or less altered to serpentine around their outer borders and along the large irregular cracks. Where they are entirely altered their outlines still remain distinct. The augite is present as very small colorless laths. The perofskite is yellow and occurs as small individual grains that are numerous throughout the rock. The biotite is of a brown color and poikilitically incloses patches of the other minerals.

PROPERTY OF AMERICAN DIAMOND MINING CO.

The peridotite exposed on a steep north hill slope in the NE. ¼ SW. ¼ sec. 14, T. 8 S., R. 25 W., belongs to the American Diamond Mining Co. The Bingen sand caps the hill and consists of about 15 feet of interbedded clay and gravel and a basal layer of ferruginous gravel conglomerate. The crest of the hill is about 100 feet above the wet-weather branch northeast of the house shown on the map (Pl. XI). The altered peridotite is exposed in shallow pits, trenches, cuts, one shaft, and one tunnel. Its superficial portion has disintegrated to a soft greenish earth, locally known as "green ground," which near the surface has in turn changed to a yellowish earth called "yellow ground." Hard rock is exposed at the surface over a few square feet near the center of the area, the exposure consisting of a few fragments of the rock protruding through the surface clay. It was reached in the shaft after passing through 32 feet of "yellow ground" and "green ground" and was then penetrated to a depth of 16 feet. It is said to have been reached in the bottom of drill holes Nos. 1, 2, and 3 after they had passed through about 30 feet of earth derived from the



MAPS SHOWING GEOLOGY OF NEW AREAS OF PERIDOTITE IN T. 8 S., R. 25 W., ARKANSAS.

peridotite. "Green ground" is reported to have been found in drill hole No. 4 below 10 feet of clay belonging to the Trinity formation, in drill hole No. 5 below 30 feet of clay belonging to the Trinity, and in other shallow drill holes between No. 4 and the tunnel.

"Black ground" derived from the peridotite overlies the disintegrated rock in places on the lower half of the slope, but elsewhere the rock is concealed to varying depths by surface clay from the Trinity and gravel from the Bingen.

Little can be judged with reference to the form of the intrusion, because of the small number of exposures. Wide dikes extend outward from the main mass at this locality, or else the main mass of the rock in passing upward through the Trinity has included rather large bodies of this formation. Probably both of these conditions exist. The disintegrated peridotite exposed at the surface at the time of the writer's visit occurs within an area of 2½ acres, but, including that in drill holes Nos. 4 and 5, it occurs at and near the surface of a much larger area. From figure 60, showing its relations to the sedimentary formations, it will be noted that the peridotite penetrates the Trinity formation and in one place is overlain by gravel belonging to the Bingen sand.

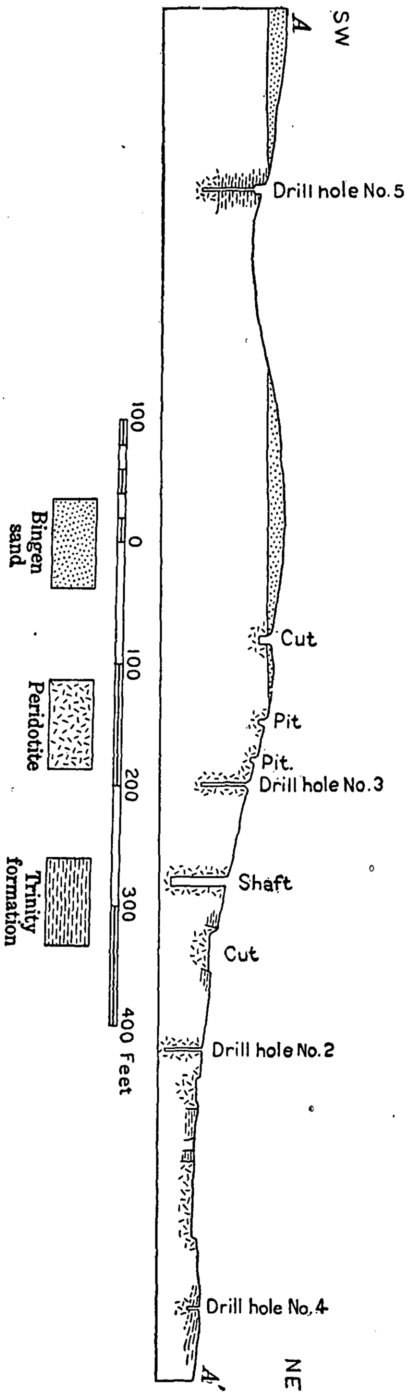


FIGURE 60.—Structure section on property of American Diamond Mining Co., sec. 14, T. 8 S., R. 25 W., Arkansas, along line *A–A'*, Plate XI. This figure shows the relations of the peridotite to the Trinity and Bingen formations.

The clay of the Trinity has in places been semivitrified to a hard gray stone for a distance of 2 feet away from its contact with the peridotite.

The hard rock, known locally as "blue ground," contains numerous small angular inclusions of black shale, derived from the Paleozoic shales through which the peridotite was intruded. These shale inclusions are present in most places in the altered rock, which here and there contains pieces of clay from the Trinity, reaching 6 inches in diameter, and waterworn quartz pebbles.

All the hard rock here is so much altered that a microscopic study is not very satisfactory. Examination of a thin section, however, indicates that the rock is similar petrographically to that of the area near the mouth of Prairie Creek and that on the property of the Kimberlite Diamond Mining & Washing Co. The olivine has completely altered to a serpentinous mineral which fills sharply defined, well-preserved cavities. Magnetite, biotite, perofskite (?), augite (?), and the colorless glass base were recognized, and the relation of these minerals to one another is apparently the same as in this rock at other areas in this region.

PROPERTY OF GRAYSON McCLOUD LUMBER CO.

The peridotite exposed in the northwest corner of sec. 23, T. 8 S., R. 25 W., is on land belonging to the Grayson McCloud Lumber Co. The exposures are at two places, one at the "Black Lick," near the northwest corner of sec. 23, and the other about 900 feet farther east, near the north line of this section.

The basal part of the Bingen sand, which is present at this locality, forms the crest of the hill and consists of 30 feet or less of waterworn gravel and a basal layer of ferruginous conglomerate. The slope is steep to the north, gentle to the west, and very gentle to the east and southeast.

The peridotite at the "Black Lick" has disintegrated near the surface to a soft yellowish-green earth retaining the original porphyritic texture of the unaltered rock. This material was penetrated to a depth of 7 feet by a pit dug by the writer. It contains a few inclusions of clay from the Trinity formation and is free from quartz sand. A great many angular fragments of sandstone are scattered over the surface near the pit. This sandstone is gray and fine grained and has green spots, being in these respects not unlike the Paleozoic sandstone in the peridotite area near the mouth of Prairie Creek. It is not known whether the fragments were hauled here, but it is likely that they were not. If not, they were included in the peridotite as it passed upward through the Paleozoic sandstones, which lie buried at possibly a considerable depth beneath the surface. A small piece of chalcedonic quartz like that in the area at the mouth of Prairie Creek was found on the surface. "Black ground" covers possibly 3 or 4 acres to the west and south of the pit, a good deal of it being probably derived from peridotite. Clay of the Trinity formation, however, is exposed in a gully about 200 feet down the slope westward from the pit.

The exposure 900 feet east of the "Black Lick" is in a pit 2 by 5 feet and 6 feet deep, dug by the writer, in a timbered area which is comparatively level over several acres. The surface material, consisting of a black gumbo soil mixed with some waterworn gravel, is 2½ feet thick. Below this is exposed 3½ feet of yellowish-green earth, derived from peridotite. The material has so disintegrated that microscopic study is impossible. Its texture is porphyritic. The phenocrysts are serpentinous pseudomorphs after olivine, the outlines of which are in many places sharply defined and well preserved.

Hand specimens of the earth from the two pits dug by the writer were compared with the disintegrated peridotite found in sec. 14 and, to judge from a macroscopic examination, are the same in color, texture, and mineral composition.

As there are no exposures of the sedimentary rocks and none of the peridotite except at the two pits, the extent of the peridotite is not known, but it is likely that the disintegrated rock in the two pits is included in a single area. If this is the case, the igneous rock will not be found at but beneath the surface where gravel belonging to the Bingen sand is present.

TIME OF THE INTRUSION.

That the peridotite of the areas herein described has penetrated the Trinity formation, which lies in a practically horizontal position, and that it is therefore younger than that formation is shown by the high dip of the contact planes between the two, by the metamorphism of the clay of the Trinity adjacent to its contact with the peridotite, and by the presence in the latter of inclusions of clay and waterworn gravel derived from the former. Branner,[1] in the report on the area of peridotite near the mouth of Prairie Creek, reached the same conclusion, which he based on the geologic relations of the small peridotite dike near the present mouth of this creek. In addition he offered "the hypothesis that this peridotite [referring to that of the Prairie Creek area and the dike just mentioned] is a simple injection which took place about the close of the Cretaceous."

In the course of the areal mapping of the rock formations of the Caddo Gap quadrangle for folio publication by A. H. Purdue and the writer in 1908 and 1911, they studied the Trinity and Bingen formations, the former as defined by Hill[2] and Veatch[3] and the latter as defined by Veatch.[3] The writer in 1912 completed the study and

[1] Branner, J. C., and Brackett, R. N., The peridotite of Pike County, Ark.: Am. Jour. Sci., 3d ser., vol. 38, 1889, p. 55; Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2, p. 390.

[2] Hill, R. T., The Neozoic geology of southwestern Arkansas: Ann. Rept. Arkansas Geol. Survey, 1888, vol. 2, pp. 1-319.

[3] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 1-442.

mapping of the contact between these formations. During the course of his work he studied clastic beds at and near the base of the Bingen sand, because they throw additional light on the age of the peridotite by containing pebbles, cobblestones, and other material derived from this rock and other igneous rocks of Arkansas. The beds in which this igneous material occurs consist of interbedded sand and water-worn pebbles and are present in places southeast of Murfreesboro, over almost the entire plateau-like area between this town and Center Point, and at least several miles to the southwest of Center Point, but because of the comparative rapidity with which this material weathers it is in few places exposed at the surface.

The best-known exposure is on Mine Creek in sec. 2, T. 9 S., R. 27 W., about 4 miles north of Nashville, Howard County. The deposit is exposed in the bed of the creek and is at least a few feet above the basal bed of gravel of the Bingen. It is a greenish sand composed of kaolinized feldspar grains and a less amount of mica, quartz, chlorite, magnetite, and red iron oxide, all of which are cemented together with calcite. Lenses of gravel that reach about 4 feet in thickness are present in the deposit at this place; they thin and thicken within short distances owing to the pronounced cross-bedding. The pebbles, some of which reach 6 inches in diameter, are thoroughly rounded and are embedded in a matrix of material like that just described. They consist of igneous rocks, mixed with a small amount of quartzite, novaculite, and millstone grit.

D. B. Sterrett,[1] who has described this occurrence, states: "Under the supposition that this rock has formed in part from the wash over a peridotite outcrop, it is being tested for diamonds." Neither Mr. Sterrett[2] nor the writer knows of any diamonds being found here. That a very small amount of the material in this sand and gravel bed is derived from peridotite is likely, but if such igneous material is present it has so disintegrated that it can not be recognized.

Thin sections of eight igneous pebbles obtained at this locality show that they are fourchite, tinguaite, and syenite.

Three sections are of fourchite not in any way dissimilar to that of the fourchite dikes near the central part of the State.

Three others are of rocks that are herein provisionally called fourchite. They differ from the typical fourchite described by Williams and Kemp[3] in that the plagioclase feldspars, mainly andesine, which are common in the groundmass of the typical fourchite, here form a large part or the most of the phenocrysts in addition to a part of the groundmass.

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[1] Sterrett, D. B., Diamonds in Arkansas: Mineral Resources U. S. for 1909, pt. 2, U. S. Geol. Survey, 1910, pp. 757–759.

[2] Personal communication.

[3] Williams, J. F., and Kemp, J. F., Igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2.

One section is of tinguaite, which is similar in texture and mineralogic composition to the tinguaite dikes near the central part of the State.[1] This rock is probably the most common igneous type among the pebbles at this locality.

One pebble of syenite was found. It is a dense dark-gray holocrystalline rock, showing abundant feldspar and a less amount of augite in the hand specimen. The thin section shows that the rock consists chiefly of feldspars (orthoclase, oligoclase-albite, and andesine) and augite, with smaller amounts of biotite, magnetite, and apatite. The pulaskite, described by Williams,[1] is intermediate between syenite and nephelite syenite, and some of it, because of the absence of nephelite, is really a syenite. The rock just described, however, does not correspond accurately to any of the pulaskite he described.

Another exposure of this gravel bed is about 1,000 feet north of this locality, on the east side of the Corinth and Nashville wagon road. Here, as in the creek, the igneous pebbles, the most common of which is tinguaite, constitute the greater part of the exposed bed. A few igneous pebbles completely altered to clay were observed in a ditch in the basal gravel of the Bingen in the northern part of the town of Center Point, and 3 miles southwest of this place a pebble of tinguaite was found in the same bed of gravel.

Near Murfreesboro the bed is thought to be of only local distribution about the masses of peridotite. It is apparently not present in the NE. ¼ SW. ¼ sec. 14, T. 8 S., R. 25 W., where gravel belonging to the Bingen sand rests upon the peridotite, nor does it seem to be present in the northwest corner of sec. 23, where this relation is probably duplicated. In these two places the bed containing the igneous material is possibly overlapped by others higher in the formation.

The bed is exposed in two small pits on the north side of Twin Knobs, near the center of sec. 22. The following section was made from the base to the top of the north knob and on its north slope, where the pits are situated.

Section of Bingen sand at Twin Knobs.

	Feet.
Gravel on top of hill and on slope. In places there are exposures of clay	60
Gravel	20
Clay. The earth shown in the two pits is near the middle of this bed. Altered serpentine grains and mica are present in the material	40
Gravel (base of Bingen sand)	10±
Clay (Trinity formation)	10+

The best exposures near Murfreesboro are in the W. ½ SW. ¼ sec. 22, T. 8 S., R. 25 W., on what is known as the Riley place, where

[1] Williams, J. F., and Kemp, J. F., loc. cit.

the deposit is exposed in a well, a pit, and two trenches. At the time of the examination the well had caved until it was only 18 feet deep. Marion Riley, who dug it, states that it was originally 41½ feet deep and that the bed under discussion extends to the bottom and the well did not go through it. The pit south of the house is 12 feet deep. The bed here consists of a greenish-yellow coarse-grained earth and shows lamination and pronounced cross-bedding. It consists principally of well-rounded grains of quartz sand intimately mixed with possibly an equal or larger amount of altered serpentine grains and a little mica in small flakes. More or less quartz gravel and fragments of gray sandstone, semivitrified clay, black shale, and altered peridotite are also present. A horizontal layer of clay and several lenses of like material occupying cross-bedding planes were observed. It has been thought by some prospectors that this material is disintegrated peridotite and that it is an eastward extension of the peridotite area near the mouth of Prairie Creek, which is about half a mile west of these exposures on the Riley place. The mineral composition of this bed and the arrangement of its material, however, show without doubt that the bed is a water-laid sediment. This origin has also been assigned by Glenn,[1] who says, in discussing the relations of this material to the peridotite, "Indications of the age of this material narrow down the period within which the extrusion of the peridotite must have occurred." In the discussion of Glenn's paper, Purdue[2] suggests post-Lower Cretaceous and pre-Upper Cretaceous age for this rock.

That the fourchite, tinguaite, and syenite in the deposit near Nashville, Ark., are the same as or similar to the corresponding types of the igneous rocks near the central part of the State has been mentioned above. The igneous rocks of central Arkansas are nephelite syenites and their associated rocks and their larger areas are near the old shore line of the Upper Cretaceous sea. All the known areas are within 110 miles of Nashville, Ark., and the nearest is less than 50 miles away from that place. Syenites, nephelite syenites, and their associated types are known in western and central Texas, but the near-shore character of the basal part of the Bingen sand in the region here described, its extent southward, and the character and relations of the equivalent formations in southern and northeastern Texas preclude the possibility that these pebbles and other igneous material were derived from any areas of these rocks in that State. Hence their only known source is the igneous masses in Arkansas, some of which may not now be exposed. As the beds described above are at the base of the Bingen sand (basal

[1] Glenn, L. C., Arkansas diamond-bearing peridotite area [abstract]: Bull. Geol. Soc. America, vol. 23, 1912, p. 726.

[2] Purdue, A. H., Bull. Geol. Soc. America, vol. 23 1912, p. 726.

Upper Cretaceous), they were laid down while the Upper Cretaceous shore line occupied this area. This indicates that the intrusion of the syenitic and monchiquitic rocks of this State took place before the invasion of the Upper Cretaceous sea. The peridotite is thought to be connected genetically with these rocks. As "the time of the intrusion of these rocks [the peridotite] was," according to Williams,[1] "not far removed from that of the syenitic and monchiquitic rocks,' it appears that the time of the intrusion of the peridotite was also prior to the invasion of the Upper Cretaceous sea.

Possibly more direct proof of the pre-Upper Cretaceous age of the peridotite intrusion than that outlined in the preceding paragraph is furnished by the clastic deposit at the base of the Bingen sand on the Riley place and in Twin Knobs, described above. The nearness of this deposit to the masses of known peridotite indicates that the altered serpentine grains and the fragments of peridotite in the base of the Bingen were derived from these masses. The pre-Upper Cretaceous age of this rock is suggested in the NE. ¼ SW. ¼ sec. 14, T. 8 S., R. 25 W., where gravel belonging to the Bingen sand rests upon it, and in the northwest corner of sec. 23, where this relation is apparently duplicated.

The intrusion of the peridotite has been shown to be later than the deposition of the Trinity formation, which is Lower Cretaceous, and earlier than that of the Bingen sand, which is basal Upper Cretaceous. As the Upper and Lower Cretaceous rocks in this region are separated by an unconformity representing an uplift sufficient to raise the region above sea level at the close of the Lower Cretaceous, it seems reasonable to assume that the intrusion of the peridotite and possibly the other igneous rocks of the State accompanied the diastrophic movements producing this elevation.

DIAMONDS.

Thus far no washing for diamonds has been done on the property of the Kimberlite Diamond Mining & Washing Co. Four diamonds of good quality are said to have been picked up on the surface, the largest weighing 4 carats. Further development work to ascertain the extent of the peridotite is now under way. At the time of the writer's visit, during November and December, 1912, this company was erecting at Kimberley a plant to wash the diamond-bearing earth to be hauled on a tramway from its peridotite area in the SW. ¼ NW. ¼ sec. 14, and from the Mauney tract on the area near the mouth of Prairie Creek.

[1] Williams, J. F., Igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2, p. 391.

A little washing for diamonds on the property of the American Diamond Mining Co. has been done in a crude way without machinery. Thus far this company reports 20 diamonds from its property.

The Grayson McCloud Lumber Co., up to the time of the writer's visit, had made no attempt to prospect its land, so as to learn the extent of the peridotite in the northwest corner of sec. 23; nor has this company done any washing to determine whether or not the disintegrated rock contains diamonds.

Inasmuch as the deposit exposed on the Riley place and on Twin Knobs is known to contain material washed from peridotite areas, whatever diamonds may have been in the eroded mass would also possibly have been transported and deposited in a like manner. This assumption is sustained by the reported discovery of a diamond on the Riley place. It is believed, however, that the possible diamond content per ton of the material at these places would as a rule be less than the diamond content per ton of the peridotite from which this material was washed. This belief is based on the presence of a great deal of quartz sand and possibly clay and other material that has been deposited in an intimate mixture with the material from the peridotite.

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. The publications marked "Exhausted" are no longer available for distribution, but may be seen at the larger libraries of the country.

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——— Platinum in southeastern Nevada: Bull. 430, 1910, pp. 192–199.

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BLAKE, W. P., Nickel; its ores, distribution, and metallurgy: Mineral Resources U. S. for 1882, 1883, pp. 399–420. 50c.

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BOUTWELL, J. M., Vanadium and uranium in southeastern Utah: Bull. 260, 1905, pp. 200–210. Exhausted.

CHRISTY, S. B., Quicksilver reduction at New Almaden [Cal.]: Mineral Resources U. S. for 1883–84, 1885, pp. 503–536. 60c.

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——— Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. 340, 1908, pp. 286–294. 30c. Partly reprinted in Bull. 450, 1911.

——— Tin, tungsten, and tantalum deposits of South Dakota: Bull. 380, 1909, pp. 131–163. 40c.

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KAY, G. F., Nickel deposits of Nickel Mountain, Oregon: Bull. 315, 1907, pp. 120-127. 50c.

KEMP, J. F., The geological relations and distribution of platinum and associated metals: Bull. 193, 1902, 95 pp. 30c.

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WEEKS, F. B., Tungsten deposits in the Snake Range, White Pine County, eastern Nevada: Bull. 340, 1908, pp. 263-270. 30c.

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, United States 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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——— The asphalt and bituminous-rock deposits of the United States: Twenty-second Ann. Rept., pt. 1, 1901, pp. 209–452. $1.60.

——— Origin and distribution of asphalt and bituminous-rock deposits in the United States: Bull. 213, 1903, pp. 296–305. 25c.

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——— Grahamite deposits of southeastern Oklahoma: Bull. 380, 1909, pp. 286–297. 40c.

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VAUGHAN, T. W., The asphalt deposits of western Texas: Eighteenth Ann. Rept., pt. 5 (continued), 1897, pp. 930–935. $1.

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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.

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